# King County

1200 King County
Courthouse
516 Third Avenue
Seattle, WA 98104

## Meeting Agenda

## King County Flood Control District

***Boardmembers: Reagan Dunn, Chair; Larry Gossett, Vice Chair; Claudia Balducci, Rod Dembowski; Jeanne Kohl-Welles, Kathy Lambert; Joe McDermott, Dave Upthegrove; Pete von Reichbauer***

**1:30 PM** | **Tuesday, February 16, 2016** | **Room 1001**

**SPECIAL MEETING**

To show a PDF of the written materials for an agenda item, click on the agenda item below.

**1. Call to Order**

**2. Roll Call**

**3. Approval of Minutes of special meeting of December 7, 2015** **page 3**

## Discussion and Possible Action

4. Election of chair, vice chair and executive committee members

**5.** FCD Resolution No. FCD2016-01 **page 5**

A RESOLUTION relating to the operations and finances of the King County Flood Control Zone District; adopting a revised 2015 budget and a revised annual District oversight budget; and amending FCD2015-07.2, Section 1, and FCD2015-07.2, Section 6.

**6.** FCD Resolution No. FCD2016-02 **page 9**

A RESOLUTION authorizing the chair to enter into a second amendment to the contract for executive director services.

**7.** FCD Resolution No. FCD2016-03 **page 15**

A RESOLUTION authorizing the chair to enter into an amendment to the agreement for government relations services.

*Sign language and communication material in alternate formats can be arranged given sufficient notice (296-1000).*
*TDD Number 296-1024.*
*ASSISTIVE LISTENING DEVICES AVAILABLE IN THE COUNCIL CHAMBERS.*

**8.** FCD Resolution No. FCD2016-04 **page 19**

A RESOLUTION adopting SEPA Procedures for the King County Flood Control Zone District.

**9.** FCD Resolution No. FCD2016-05 **page 39**

A RESOLUTION relating to the Green River System-Wide Improvement Framework; directing the King County Director of Water and Land Resources to submit the Interim SWIF to the United States Army Corps of Engineers; providing for a Corridor Plan for the Lower Green River; establishing and appointing members of a Lower Green River Corridor Plan Advisory Committee; and authorizing a programmatic environmental impact statement SEPA process.

**10.** FCD Motion No. FCD16-01 **page 475**

A MOTION establishing the 2016 state legislative agenda for the King County Flood Control Zone District.

## 11. Adjournment

# King County

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## Meeting Minutes - Final Without Extra Items

## King County Flood Control District

***Boardmembers: Reagan Dunn, Chair; Larry Gossett, Vice Chair; Rod Dembowski; Jane Hague; Kathy Lambert; Joe McDermott, Larry Phillips; Dave Upthegrove; Pete von Reichbauer***

**1:30 PM** | **Monday, December 7, 2015** | **Room 1001**

**DRAFT MINUTES**
**SPECIAL MEETING**

### 1. Call to Order

*The meeting was called to order at 1:44 p.m.*

### 2. Roll Call

**Present:** 6 - Ms. Lambert, Ms. Hague, Mr. von Reichbauer, Mr. Dunn, Mr. McDermott and Mr. Dembowski

**Excused:** 3 - Mr. Gossett, Mr. Phillips and Mr. Upthegrove

### 3. Approval of Minutes of November 16, 2015

*Boardmember McDermott moved to approve the minutes of the November 16, 2015 meeting as presented. Seeing no objection, the Chair so ordered.*

## Discussion and Possible Action

**Items 4 and 5 were considered as a consent agenda**

### 4. FCD Resolution No. FCD2015-14

A RESOLUTION authorizing the chair to enter into an amendment to the contract for accounting services.

*Kjris Lund, Executive Director, briefed the Board.*

**A motion was made by Boardmember McDermott that this FCD Resolution be Passed. The motion carried by the following vote:**

**Yes:** 6 - Ms. Lambert, Ms. Hague, Mr. von Reichbauer, Mr. Dunn, Mr. McDermott and Mr. Dembowski

**Excused:** 3 - Mr. Gossett, Mr. Phillips and Mr. Upthegrove

**5.** **FCD Resolution No. FCD2015-15**

A RESOLUTION authorizing the chair to enter into an amendment to the agreement for special counsel legal services.

*Kjris Lund, Executive Director, briefed the Board.*

**A motion was made by Boardmember McDermott that this FCD Resolution be Passed. The motion carried by the following vote:**

**Yes:** 6 - Ms. Lambert, Ms. Hague, Mr. von Reichbauer, Mr. Dunn, Mr. McDermott and Mr. Dembowski

**Excused:** 3 - Mr. Gossett, Mr. Phillips and Mr. Upthegrove

**6.** **FCD Resolution No. FCD2015-16**

A RESOLUTION approving an interlocal agreement with King County regarding flood protection projects and services.

*Kjris Lund, Executive Director, briefed the Board.*

*Boardmember McDermott moved Amendment 1. The motion passed by the following vote:*
*Votes: Yes: 6 - Mr. Dembowski, Mr. Dunn, Ms. Hague, Ms. Lambert, Mr. McDermott and Mr. von Reichbauer*
*No: 0*
*Excused: 3 - Mr. Gossett, Mr. Phillips, Mr. Upthegrove*

**This matter was Passed as Amended**

**Yes:** 6 - Ms. Lambert, Ms. Hague, Mr. von Reichbauer, Mr. Dunn, Mr. McDermott and Mr. Dembowski

**Excused:** 3 - Mr. Gossett, Mr. Phillips and Mr. Upthegrove

## 7. Adjournment

*The meeting adjourned at 1:55 p.m.*

Approved this _____ day of _____.

_____

Clerk's Signature

# KING COUNTY

1200 King County Courthouse
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Seattle, WA 98104

## Signature Report

**February 9, 2016**

**FCD Resolution**

**Proposed No.** FCD2016-01.1 **Sponsors**

A RESOLUTION relating to the operations and finances of the King County Flood Control Zone District; adopting a revised 2015 budget and a revised annual District oversight budget; and amending FCD2015-07.2, Section 1, and FCD2015-07.2, Section 6.

WHEREAS, the King County Flood Control Zone District ("District") adopted its 2015 work program, budget, operating budget, capital budget, six-year capital improvement program, oversight budget and subregional opportunity fund allocations in Resolution FCD2014-14.3, and amended it in Resolution FCD2015-07.2; and

WHEREAS, in 2015 the executive committee requested the District's legal counsel and the District's financial accounting firm to perform additional services, which resulted in charges for services in excess of the appropriations in the 2015 budget; and

WHEREAS, pursuant to RCW 86.15.140, the District held a public hearing on a supplemental budget for such services on February 22, 2016; and

WHEREAS, the board of supervisors desires to adopt amendments to the District's 2015 budget and District's oversight budget with regard to the services of the District's legal counsel and District's financial accounting firm;

BE IT RESOLVED BY THE BOARD OF SUPERVISORS OF THE KING COUNTY FLOOD CONTROL ZONE DISTRICT:

SECTION 1. The Board adopts a revised 2015 budget for the District, as set forth in Attachment A to this resolution, titled "2015 Revised Annual Budget," and amends Section 1 of FCD2015-07.2 accordingly.

SECTION 2. The Board adopts a revised 2015 District oversight budget for the District, as set forth in Attachment B to this resolution, titled "2015 Revised Annual District Oversight Budget," and amends Section 6 of FCD2015-07.2 accordingly.

KING COUNTY FLOOD CONTROL ZONE DISTRICT
KING COUNTY, WASHINGTON

_____

Reagan Dunn, Chair

ATTEST:

_____

Anne Noris, Clerk of the Board

**Attachments:** A. 2015 Revised Annual Budget 1-25-16, B. 2015 Revised Annual District Oversight Budget 1-25-16

## *2015 Revised Annual Budget*

### Attachment A

1-25-16

| Program | 2015 Adopted | 2015 Revised |
|---|---|---|
| Flood District Administration | 647,291 | 704,687 |
| Maintenance and Operation | 9,335,891 | 9,335,891 |
| Construction and Improvements | 132,567,667 | 132,567,667 |
| Bond Retirement and Interest | $0 | $0 |
| **Total** | 142,550,849 | 142,608,245 |

# King County Flood Control District

# Revised 2015 Annual District Oversight Budget

## Attachment B

1-25-16

| | 2015 Adopted | 2015 Revised |
|---|---|---|
| Management & Support | $257,937 | $257,937 |
| Rent and Equipment | $0 | $0 |
| Legal Services | $89,604 | $135,000 |
| Accounting | $82,400 | $94,400 |
| State Auditor | $16,391 | $16,391 |
| Other Professional Services | $105,000 | $105,000 |
| Expenses | $16,391 | $16,391 |
| Insurance | $79,568 | $79,568 |
| **Total** | **$647,291** | **$704,687** |

# KING COUNTY

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## Signature Report

**February 9, 2016**

**FCD Resolution**

**Proposed No.** FCD2016-02.1 **Sponsors**

A RESOLUTION authorizing the chair to enter into a second amendment to the contract for executive director services.

WHEREAS, the King County Flood Control Zone District ("District") has entered into a contract for executive director services with Lund Consulting, Inc.; and

WHEREAS, the District desires to amend the contract as set forth in Attachment A to this resolution; now, therefore

BE IT RESOLVED BY THE BOARD OF SUPERVISORS OF THE KING COUNTY FLOOD CONTROL ZONE DISTRICT:

SECTION 1. The chair of the King County Flood Control Zone District is authorized to enter into the "Second Amendment to Contract for Consultant Services," Attachment A to this resolution.

KING COUNTY FLOOD CONTROL ZONE DISTRICT
KING COUNTY, WASHINGTON

_____

Reagan Dunn, Chair

ATTEST:

_____

Anne Noris, Clerk of the Board

**Attachments:** A. Second Amendment to Contract for Consultant Services

Attachment A

**SECOND AMENDMENT TO**
**CONTRACT FOR CONSULTANT SERVICES**
**KING COUNTY FLOOD CONTROL ZONE DISTRICT**

This AMENDMENT amends sections 2 and 3 of the Contract for Consultant Services ("Contract") between the King County Flood Control Zone District, King County, Washington, a municipal corporation of the State of Washington ("District") and Lund Consulting, Inc. ("Consultant") as follows:

A. Amendment of Section 2. Section 2 of the Contract is amended to read as follows:

2. Compensation and Method of Payment.

The District shall pay Consultant according to the rates set forth in Sections I and II of Exhibit "A" to the Second Amendment to Contract for Consultant Services and in total amounts as described in Exhibit "A" (dated ~~July 20, 2015~~ January 25, 2016)~~.~~; provided, that the total amounts for the period ~~April 1, 2015~~ February 29, 2016 through ~~February 28~~ May 31, 2016 shall not exceed ~~$210,000~~ 74,000. ~~Consultant's authorization to perform work in total amount of more than $210,000 is conditioned upon appropriation of additional funds by the District Board of Supervisors.~~

The Consultant shall complete and return to the District Exhibit "C," Tax Identification Number," prior to or along with the first billing invoice. The District shall pay the Consultant for services rendered within ten (10) days after Board voucher approval.

B. Amendment of Section 3. Section 3 of the Contract is amended to read as follows:

3. Duration of Agreement. This Agreement shall be in full force and effect for a period commencing on April 1, 2015 and ending on ~~February 28~~ May 31, 2016, unless sooner terminated or extended under the provisions of this Agreement. Time is of the essence of this Agreement in each and all of its provisions in which performance is required.

IN WITNESS WHEREOF, the parties hereto have executed this Amendment on the dates written below:

Attachment A

| KING COUNTY FLOOD CONTROL ZONE DISTRICT | CONSULTANT |
|---|---|
| By: _____ | By: _____ |
| Title: Board Chair | Title: _____ |
| Date: _____ | Date: _____ |

Attachment A

Exhibit A
Second Amendment
(January 25, 2016)

Section 1. Tasks

1. Oversee District operations working with Executive Committee
    a. Work with Executive Committee chair to set agendas for Executive Committee meetings
    b. Work with chair to set agendas for Board
    c. Monitor assignments with consultants, member staff, central communications staff, and King County WLRD
    d. Keep Executive Committee informed of emerging issues

2. Perform policy analysis on behalf of District
    a. Work with Executive Committee staff
    b. Inclusive of SWIF, Farm, Fish and Flood Task Force, Basin plans

3. Oversee compliance
    a. Track compliance with adopted resolutions
    b. Serve as liaison between District and State Auditor

4. District Spokesperson
    a. Represent District with Advisory Committee
    b. Represent District with other ad hoc advisory committees
    c. Represent District with media as requested
    d. Represent District with general public inquiries

5. Administrative Services
    a. Draft resolutions with direction from Executive Director
    b. Marshall and assemble information for meeting packets
    c. Coordinate with Clerk to ensure records are maintained
    d. Process paperwork such as business license, filings, insurance, invoices, warrants
    e. Schedule meetings

6. Work with legal counsel on real estate matters
    a. Manage signature processes and records

Attachment A

Section 2. Rates

| CLASSIFICATION | STAFF MEMBER | 2015 BILLING RATES | BILLING RATE FOR KING COUNTY | ESTIMATE HOURS PER MONTH | ESTIMATE MONTHLY COST |
|---|---|---|---|---|---|
| Lund Consulting, Inc. | | | | | |
| Principal | Kjristine Lund | $300.00 | $235.00 | 100 | $23,500 |

**rates includes salary, sick leave, vacation leave, health insurance, disability insurance, state and local taxes, office rent, phones, computers, normal office supplies, overhead.*

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# KING COUNTY

## Signature Report

**February 9, 2016**

**FCD Resolution**

**Proposed No.** FCD2016-03.1 **Sponsors**

A RESOLUTION authorizing the chair to enter into an amendment to the agreement for government relations services.

WHEREAS, the King County Flood Control Zone District ("District") has entered into an agreement for government relations services with W2 Advocates; and

WHEREAS, the District desires to amend the agreement for government relations services as set forth in Attachment A to this resolution; now, therefore

BE IT RESOLVED BY THE BOARD OF SUPERVISORS OF THE KING COUNTY FLOOD CONTROL ZONE DISTRICT:

SECTION 1. The chair of the King County Flood Control Zone District is authorized to enter into the "2016 Amendment to Contract for Consultant Services," Attachment A to this resolution.

KING COUNTY FLOOD CONTROL ZONE DISTRICT
KING COUNTY, WASHINGTON

_____

Reagan Dunn, Chair

ATTEST:

_____

Anne Noris, Clerk of the Board

**Attachments:** A. 2016 Amendment to Contract for Consultant Services

**2016 AMENDMENT TO**
**CONTRACT FOR CONSULTANT SERVICES**
**KING COUNTY FLOOD CONTROL ZONE DISTRICT**

This 2016 AMENDMENT amends Section 2, Section 3, and Exhibit "A" (Scope of Services) of the Contract for Consultant Services ("Contract") between the King County Flood Control Zone District, King County, Washington, a municipal corporation of the State of Washington ("District") and W2Advocates ("Consultant") as follows:

A. Amendment of Section 2. Effective February 22, 2016, Section 2 of the Contract is amended as follows:

2. Compensation and Method of Payment.

The District shall pay Consultant according to the rates set forth in amounts as described in Exhibit "A" to the ~~2015~~ 2016 Amendment to this Agreement; provided, that the total amount shall not exceed ~~$95,000~~ 132,500.

B. Amendment of Section 3. Effective February 22, 2016, Section 3 of the Contract is amended as follows:

3. Duration of Agreement. This Agreement shall be in full force and effect for a period commencing on December 16, 2014 and ending ~~February 28~~ July 30, 2016, unless sooner terminated or extended under the provisions of this Agreement. Time is of the essence of this Agreement in each and all of its provisions in which performance is required.

C. Amendment of Exhibit "A." Effective February 22, 2016, Exhibit "A" to the Contract for Consultant Services is amended as set forth in Exhibit "A" attached to this 2016 Amendment.

IN WITNESS WHEREOF, the parties hereto have executed this Amendment on the dates written below:

| KING COUNTY FLOOD CONTROL ZONE DISTRICT | CONSULTANT |
|---|---|
| By: _____ | By: _____ |
| Title: Board Chair | Title: _____ |
| Date: _____ | Date: _____ |

Exhibit A
Scope of Work and Budget
Amendment #1: W2Advocates

**Scope of Work**

**Task 1. Federal Agency and Delegation Outreach**

W2A will work with KCFCD in conjunction with the development of the SWIF project progress to engage the US Army Corps of Engineers on the System Wide Improvement Framework on issues both regionally and in DC as they arise. W2A will also brief the federal delegation on the SWIF process to ensure they are informed about current progress and able to advocate on behalf of KCFCD should it be needed.

- Arrange meeting with federal delegation
- Facilitate meetings with USACE headquarters

**Task 2. Washington Waters Legislation**

We will continue to monitor and engage in the Washington Waters legislation as conversations continue over the interim and as additional proposals are developed.

- Advocate on behalf of KCFCD priorities in Olympia. (Jan –Feb)
- Work with and coordinate stakeholder activities supporting KCFCD priorities. (Jan – Feb)
- Coordinate testimony on KCFCD issues. (Jan – Feb)
- Monitor issues impacting KCFCD. (Jan – Feb)
- Report to Supervisors and attend meetings as requested. (Jan – Feb)
- Participate in weekly update calls with KCFCD staff. (Jan – Feb)
- Provide bill tracking document on weekly basis. (Jan – Feb)

**Task 3. Assist with Local Flood and Habitat Projects**

W2A will continue to assist KCFCD with local flood and habitat projects as needed.

**Budget**

Monthly retainer with a flat fee of $7500 per month for the contract period beginning September 1, 2015 through July 30, 2016. Out of pocket expenses are included in the above fee. Travel costs associated with trip to Washington DC to meet with delegation and USACE with Board Chair and Vice Chair will be billed separately.

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# KING COUNTY

## Signature Report

**February 9, 2016**

**FCD Resolution**

**Proposed No.** FCD2016-04.1 **Sponsors**

A RESOLUTION adopting SEPA Procedures for the King County Flood Control Zone District.

WHEREAS, the Washington State Department of Ecology has adopted rules for implementation of the state Environmental Policy Act ("SEPA"); and

WHEREAS, pursuant to RCW 43.21C.120 and WAC 197-11-904 the King County Flood Control Zone District ("District") gave notice of adoption of its SEPA procedures on February 3, 2016, in the Seattle Times, a newspaper of general circulation in the District, and held a public hearing on the proposed SEPA procedures on _____, 2016; now, therefore

BE IT RESOLVED BY THE BOARD OF SUPERVISORS OF THE KING COUNTY FLOOD CONTROL ZONE DISTRICT:

SECTION 1. Authority. The District adopts this resolution under the state Environmental Policy Act ("SEPA"), RCW 43.21C.120 and WAC 197-11-904. This resolution contains the District's SEPA procedures and policies. The SEPA rules, chapter 197-11 WAC, must be used in conjunction with this resolution.

SECTION 2. Adoption by Reference. Sections 2 through 7 contain the basic requirements that apply to the SEPA process. The District adopts the following sections of Chapter 197-11 WAC by reference:

WAC

| | |
|---|---|
| 197-11-040 | Definitions. |
| 197-11-050 | Lead agency. |
| 197-11-055 | Timing of the SEPA process. |
| 197-11-060 | Content of environmental review. |
| 197-11-070 | Limitations of actions during SEPA process. |
| 197-11-080 | Incomplete or unavailable information. |
| 197-11-090 | Supporting documents. |
| 197-11-100 | Information required of applicants. |
| 197-11-158 | SEPA/GMA project review - Reliance on existing plans, laws, and regulations |
| 197-11-210 | SEPA/GMA integration |
| 192-11-220 | SEPA/GMA definitions. |
| 197-11-228 | Overall SEPA/GMA integration procedures. |
| 197-11-230 | Timing of an integrated GMA/SEPA process. |
| 197-11-232 | SEPA/GMA integration procedures for preliminary planning, environmental analysis, and expanded scoping. |
| 197-11-235 | SEPA/GMA integration documents. |
| 197-11-238 | SEPA/GMA integration monitoring. |
| 197-11-250 | SEPA/Model Toxic Control Act integration. |
| 197-11-253 | SEPA lead agency for MTCA actions. |
| 197-11-256 | Preliminary evaluation. |
| 197-11-259 | Determination of nonsignificance for MTCA remedial actions. |

197-11-262 Determination of significance and EIS for MTCA remedial actions.

197-11-265 Early scoping for MTCA remedial actions.

197-11-268 MTCA interim actions.

SECTION 3. Additional Definitions. In addition to those definitions contained in WAC 197-11-700 through WAC 197-11-799, when used in this resolution, the following terms shall have the following meanings, unless the context indicates otherwise:

A. “"Board" means District board of supervisors.

B. "DNS" means determination of nonsignificance.

C. "DS" means determination of significance.

D. "EIS" means environment impact statement.

E. "Executive Committee" means the District executive committee.

F. “Executive Director” means the District executive director.

G. "SEPA rules" means chapter 197-11 WAC adopted by the Department of Ecology.

SECTION 4. Responsible Official.

A. The responsible official shall be the Executive Director or designee, or if there is no Executive Director, the chair of the Board or designee. When the Executive Director or the chair designates another person as responsible official, the Executive Director or the chair shall be guided in making such designation by the nature of the proposal and the administrative decision making process normally used by the District.

B. For all proposals for which the District is the lead agency, the responsible official shall make the threshold determination, supervise scoping, prepare any required EIS and perform any other functions assigned to the "lead agency" or "responsible official" by this resolution.

C. The District shall retain all documents required by the SEPA rules and shall make them available in accordance with chapter 42.56 RCW.

D. All decisions of the responsible official and the District relating to interpretation and application of this resolution shall be accorded substantial deference.

SECTION 5. Lead Agency Determination and Responsibilities.

A. The District shall be deemed to initiate any "proposal" (as that term is defined in WAC 197-11-784), whether implemented by District employees and District contractors, or implemented by King County as contractor to the District. A proposal means a proposed "action" (as that term is defined in WAC 197-11-704). An action is either a project action or a nonproject action (see WAC 197-11-704).

B. King County shall be the lead agency for a proposal that is a project action, unless determined otherwise by the Board or the Executive Committee. When King County is the lead agency for a project action, King County shall comply with the King County SEPA procedures and policies, as set forth in Chapter 20.44 KCC.

C. The District shall be the lead agency for a proposal that is a nonproject action, unless determined otherwise by the Board or the Executive Committee. When the District is the lead agency for a nonproject action, the responsible official shall supervise

compliance with the threshold determination requirements, and if an EIS is necessary, shall supervise preparation of the EIS.

D. For the Green River System-Wide Improvement Framework Plan, interim or final, and for the Lower Green River Corridor Plan, the District shall be the lead agency, unless subsequently determined otherwise by the Board or the Executive Committee.

E. If the District receives a lead agency determination made by another agency, other than King County, for a proposal, and the determination in the opinion of the District appears to be inconsistent with the criteria of WAC 197-11-253 or 197-11-922 through 197-11-940, the District may object to the determination. Any objection shall be made to the agency originally making the determination and resolved within 15 days of receipt of the determination, or the District shall petition the Department of Ecology for a lead agency determination under WAC 197-11-946 immediately following the 15-day time period. The petition shall be initiated by the responsible official.

F. When the District is lead agency for a Model Toxic Control Act ("MTCA") remedial action, the Department of Ecology shall be provided an opportunity under WAC 197-11-253(5) to review the environmental documents prior to public notice being provided. If SEPA and MTCA documents are issued together with one public comment period under WAC 197-11-253(6), the District shall jointly with the Department of Ecology decide which entity receives the comment letters and how copies of the comment letters will be distributed to the other agency.

SECTION 6. Timing Considerations.

A. The responsible official shall begin any required environmental review for proposals at the earliest point in the planning and decision making process when the

principal features of the proposal and its probable environmental impacts are reasonably identified.

B. To the extent that the District establishes any advisory body for purposes of making a recommendation on a proposal to the Board or Executive Committee, the responsible official shall provide such bodies with any relevant environmental documents before any final recommendation is transmitted to the Board or Executive Committee.

C. Any environmental review may be organized in phases as specified in WAC 197-11-060(5).

D. In all cases not otherwise covered, the timing of the District's environmental review for proposals shall be as specified on an individual, case by case basis by the responsible official, consistent with this resolution.

SECTION 7. Emergency Actions. Any action which in the opinion of the responsible official must be undertaken immediately, or within a time too short to allow full compliance with the provisions of this resolution, to avoid an imminent danger to property (public or private), or to prevent an imminent threat of serious environmental degradation, shall be exempt from the procedural requirements of SEPA, the SEPA rules and this resolution.

SECTION 8. Categorical Exemptions and Threshold Determinations - Adopted by Reference.

A. Sections 8 through 10 contain rules for deciding whether a proposal has a "probable significant, adverse environmental impact," thereby requiring preparation of an EIS. This section also contains rules for evaluating the impacts of proposals not requiring an EIS. The District adopts the following sections by reference:

WAC

197-11-300 Purpose of this part.

197-11-305 Categorical exemptions.

197-11-310 Threshold determination required.

197-11-315 Environmental checklist.

197-11-330 Threshold determination process.

197-11-335 Additional information.

197-11-340 Determination of nonsignificance (DNS).

197-11-350 Mitigated DNS.

197-11-355 Optional DNS process.

197-11-360 Determination of significance (DS) / initiation of scoping.

197-11-390 Effect of threshold determination.

B. Use of exemptions.

1. The responsible official shall determine whether the proposal is exempt. The official's determination that a proposal is exempt shall be final and not subject to administrative review. If a proposal is exempt, none of the procedural requirements of this resolution shall apply to the proposal. The responsible official shall not require completion of an environmental checklist for an exempt proposal.

2. In determining whether a proposal is exempt, the responsible official shall make certain that the proposal is properly defined and shall identify the governmental licenses required (WAC 197-11-060).

3. If a proposal includes both exempt and nonexempt actions, the responsible official may authorize exempt actions prior to compliance with the procedural requirements of this resolution, except that:

a. The responsible official shall not give authorization for:

i. Any nonexempt action;

ii. Any action that would have an adverse environmental impact; or

iii. Any action that would limit the choice of alternatives; and

b. The responsible official may withhold approval of exempt actions that would lead to modification of the physical environment, when such modification would serve no purpose if nonexempt actions were not approved.

SECTION 9. Environmental Checklist. A completed environmental checklist in the form provided by WAC 197-11-960 shall be prepared for any proposal not specifically exempted in this resolution; provided, that a checklist is not needed if the responsible official determines that an EIS is required, SEPA compliance has been completed or SEPA compliance has been initiated by another agency.

SECTION 10. Mitigated DNS.

A. As provided in this section and in WAC 197-11-350, the responsible official may issue a DNS based on conditions attached to the proposal by the responsible official.

B. Mitigation measures which justify issuance of a mitigated DNS may be incorporated in the DNS by reference to District staff reports, studies or documents.

C. A mitigated DNS is issued under WAC 197-11-340(2), which requires a 14-day comment period and public notice.

D. Mitigation measures incorporated in the mitigated DNS shall be deemed conditions of approval of the permit or approval decision and may be enforced in the same manner as any term or condition of the permit or approval, or enforced in any manner specifically prescribed by the District.

E. If the responsible official's tentative decision on a permit or approval does not include mitigation measures that were incorporated in a mitigated DNS for the proposal, the responsible official should evaluate the threshold determination to assure consistency with WAC 197-11-340(3)(a) (withdrawal of DNS).

SECTION 11. Environmental Impact Statements - Adoption by Reference.

A. The District adopts the following sections by reference:

| WAC | |
|---|---|
| 197-11-400 | Purpose of EIS. |
| 197-11-402 | General requirements. |
| 197-11-405 | EIS types. |
| 197-11-406 | EIS timing. |
| 197-11-408 | Scoping. |
| 197-11-410 | Expanded scoping. |
| 197-11-420 | EIS preparation. |
| 197-11-425 | Style and size. |
| 197-11-430 | Format. |
| 197-11-435 | Cover letter or memo. |
| 197-11-440 | EIS contents. |
| 197-11-442 | Contents of EIS on nonproject proposals. |

197-11-443 EIS Contents when prior nonproject EIS.

197-11-444 Elements of the environment.

197-11-448 Relationship of EIS to other considerations.

197-11-450 Cost benefit analysis.

197-11-455 Issuance of DEIS.

197-11-460 Issuance of FEIS.

B. Preparation of draft and final EISs (DEIS and FEIS) and draft and final supplemental EISs (SEIS) is the responsibility of the responsible official. Before the District issues an EIS, the responsible official shall be satisfied that it complies with this resolution and chapter 197-11 WAC.

C. The DEIS and FEIS or draft and final SEIS shall be prepared by District staff or District contractors.

SECTION 12. Commenting - Adoption by Reference.

A. This section contains rules for consulting, commenting and responding on all environmental documents under SEPA, including rules for public notice and hearings.

B. The District adopts the following sections by reference:

WAC

197-11-500 Purpose of this part.

197-11-502 Inviting comment.

197-11-504 Availability and cost of environmental documents.

197-11-508 SEPA register.

197-11-510 Public notice.

197-11-535 Public hearings and meetings.

197-11-545 Effect of no comment.

197-11-550 Specificity of comments.

197-11-560 FEIS response to comments.

197-11-570 Consulted agency costs to assist lead agency.

C. Whenever the District issues a DNS under WAC 197-11-340 (2) or a DS under WAC 197-11-360(3), the District shall give public notice as follows:

1. If public notice is required for the permit or approval, the notice shall state whether a DS or DNS has been issued and when comments are due.

2. If no public notice is required for the permit or approval, the District shall give notice of the DNS or DS by publishing notice in a newspaper of general circulation in the District.

D. Whenever the District issues a DS under WAC 197-11-360(3), the District shall state the scoping procedure for the proposal in the DS as required in WAC 197-11-408 and in the public notice.

E. Whenever the District issues a DEIS under WAC 197-11-455(5) or a SEIS under WAC 197-11-620, notice of the availability of documents shall be given by indicating the availability of the DEIS in any public notice required for a nonexempt license or approval and publishing notice in a newspaper of general circulation in the District.

F. Whenever possible, the District shall integrate the public notice required under this section with existing notice procedures for the District's nonexempt permits or approvals required for the proposal.

G. The responsible official shall be responsible for preparation of written comments for the District in response to a consultation request prior to a threshold determination participation in scoping and reviewing a DEIS.

H. The responsible official shall be responsible for the District's compliance with WAC 197-11-550 whenever the District is a consulted agency and is authorized to develop operating procedures that will ensure timely responses to consultation requests.

SECTION 13. Using Existing Environmental Documents.

A. This section contains rules for using and supplementing existing environmental documents prepared under SEPA or the National Environmental Policy Act ("NEPA") for the District's own environmental compliance.

B. The District adopts the following sections by reference:

| WAC | |
|---|---|
| 197-11-600 | When to use existing environmental documents. |
| 197-11-610 | Use of NEPA documents. |
| 197-11-620 | Supplemental environmental impact statement¬ procedures. |
| 197-11-625 | Addenda-Procedures. |
| 197-11-630 | Adoption-Procedures. |
| 197-11-635 | Incorporation by reference-Procedures. |
| 197-11-640 | Combining documents. |

SECTION 14. SEPA Agency Decisions.

A. Sections 14 through 16 contain rules and policies for SEPA's substantive authority, such as decisions to mitigate or reject proposals as a result of SEPA, and for appealing SEPA determinations to agencies or courts.

B. The District adopts the following sections by reference:

WAC

197-11-650 Purpose of this part.

197-11-655 Implementation.

197-11-660 Substantive authority and mitigation.

197-11-680 Appeals.

SECTION 15. Substantive Authority.

A. The following policies, plans, rules and regulations, and all amendments thereto, are designated as potential bases for the exercise of the District's substantive authority under SEPA:

1. The policies of RCW 43.21C.020(2).

2. The District comprehensive plan.

3. District cooperative watershed management plans.

4. Federal, State or County laws, regulations, policies and practices applicable to a proposal.

5. For proposals implemented by King County, the policies, plans, rules and regulations designated in KCC 20.44.080 as substantive authority for King County under SEPA.

B. Any decision to approve, deny or approve with conditions a proposal shall comply with the requirements of RCW 43.21C.060.

SECTION 16. Appeals.

A. The District's threshold determination and EIS shall be issued before the decision on the proposal. Any person may appeal a threshold determination or the

adequacy of a final EIS by filing a notice of appeal within the time period set forth in KCC 20.24.090 and in accordance with requirements and procedures of the King County office of the hearing examiner in KCC 20.24.090 - 20.24.210 (to the extent applicable); provided, that the notice of appeal shall be filed the clerk of the Board, the duties and responsibilities of the County department or division shall be satisfied by the Executive Director or designee, and the decision of the hearing examiner shall be final unless appealed to superior court in accordance with KCC 20.24.240.

B. The appeal services of the office of the hearing examiner shall be provided for the District in accordance with the interlocal agreement between the District and King County regarding flood protection services, and shall be paid for by the District in accordance with the interlocal agreement.

SECTION 17. Notice - Statute of Limitations. The District may publish a notice of action pursuant to RCW 43.21C.080 for any action. The form of the notice shall be substantially in the form provided in WAC 197-11-990. The notice shall be published by the District pursuant to RCW 43.21C.080.

SECTION 18. Definitions - Adoption by Reference.

A. This section contains uniform usage and definitions of terms under SEPA.

B. The District adopts the following sections by reference, as supplemented by section 3:

WAC

197-11-700 Definitions.

197-11-702 Act.

197-11-704 Action

| | | |
|---|---|---|
| 312 | 197-11-706 | Addendum. |
| 313 | 197-11-708 | Adoption. |
| 314 | 197-11-710 | Affected tribe. |
| 315 | 197-11-712 | Affecting. |
| 316 | 197-11-714 | Agency. |
| 317 | 197-11-716 | Applicant. |
| 318 | 197-11-718 | Built environment. |
| 319 | 197-11-720 | Categorical exemption. |
| 320 | 197-11-721 | Closed record appeal. |
| 321 | 197-11-712 | Consolidated appeal. |
| 322 | 197-11-724 | Consulted agency. |
| 323 | 197-11-726 | Cost-benefit analysis. |
| 324 | 197-11-728 | County/city. |
| 325 | 197-11-730 | Decision maker. |
| 326 | 197-11-732 | Department. |
| 327 | 197-11-734 | Determination of nonsignificance (DNS). |
| 328 | 197-11-736 | Determination of significance (DS). |
| 329 | 197-11-738 | EIS. |
| 330 | 197-11-740 | Environment. |
| 331 | 197-11-742 | Environmental checklist. |
| 332 | 197-11-744 | Environmental document. |
| 333 | 197-11-746 | Environmental review. |
| 334 | 197-11-750 | Expanded scoping. |

| | | |
|---|---|---|
| 335 | 197-11-752 | Impacts. |
| 336 | 197-11-754 | Incorporation by reference. |
| 337 | 197-11-756 | Land covered by water. |
| 338 | 197-11-758 | Lead agency. |
| 339 | 197-11-760 | License. |
| 340 | 197-11-762 | Local agency. |
| 341 | 197-11-764 | Major action. |
| 342 | 197-11-766 | Mitigated DNS. |
| 343 | 197-11-768 | Mitigation. |
| 344 | 197-11-770 | Natural environment. |
| 345 | 197-11-772 | NEPA. |
| 346 | 197-11-774 | Nonproject. |
| 347 | 197-11-775 | Open record hearing. |
| 348 | 197-11-776 | Phased review. |
| 349 | 197-11-778 | Preparation. |
| 350 | 197-11-780 | Private project. |
| 351 | 197-11-782 | Probable. |
| 352 | 197-11-784 | Proposal. |
| 353 | 197-11-786 | Reasonable alternative. |
| 354 | 197-11-788 | Responsible official. |
| 355 | 197-11-790 | SEPA. |
| 356 | 197-11-792 | Scope. |
| 357 | 197-11-192 | Scoping. |

197-11-794 Significant.

197-11-796 State agency.

197-11-797 Threshold determination.

197-11-799 Underlying governmental action.

SECTION 19. Categorical Exemptions. The District adopts by reference the following rules for categorical exemptions as supplemented in this resolution:

WAC

197-11-800 Categorical exemptions.

197-11-880 Emergencies.

197-11-890 Petitioning DOE to change exemptions.

SECTION 20. Agency Compliance - Adoption by Reference.

A. This section contains rules for District compliance with SEPA, including rules for charging fees under the SEPA process, designating categorical exemptions that do not apply within critical areas, listing agencies with environmental expertise, selecting the lead agency and applying these rules to current District activities.

B. The District adopts the following sections by reference:

WAC

197-11-900 Purpose of this part.

197-11-902 Agency SEPA policies.

197-11-916 Application to ongoing actions.

197-11-920 Agencies with environmental expertise.

197-11-922 Lead agency rules.

197-11-924 Determining the lead agency.

197-11-926 Lead agency for governmental proposals.

197-11-928 Lead agency for public and private proposals.

197-11-934 Lead agency for private projects requiring licenses from a local agency, not a county/city and one or more state agencies.

197-11-938 Lead agencies for specific proposals.

197-11-940 Transfer of lead agency status to a state agency.

197-11-942 Agreements on lead agency status.

197-11-944 Agreements on lead agency duties.

197-11-946 DOE resolution of lead agency disputes.

197-11-948 Assumption of lead agency status.

C. The District shall require the following fees for its activities in accordance with the provisions of this resolution:

1. Threshold determination. Except when the District is the proponent of a proposal, for every environmental checklist the District will review when it is lead agency, the District shall collect a fee of $450.00 from the proponent of the proposal prior to undertaking the threshold determination. The time periods provided by this resolution for making a threshold determination shall not begin to run until payment of the fee.

2. Environmental impact statement.

a. Except when the District is the proponent of a proposal, when the District is the lead agency for a proposal requiring an EIS and the responsible official determines that the EIS shall be prepared by the District, the District may charge and collect a reasonable fee from any applicant to cover costs incurred by the District in

preparing the EIS. The responsible official shall advise the applicant of the projected costs for the EIS prior to actual preparation, and the applicant shall post bond or otherwise ensure payment of such costs.

b. The responsible official may determine that the District will contract directly with a consultant for preparation of an EIS, or a portion of the EIS, for activities initiated by some persons or entity other than the District and may bill such costs and expenses directly to the applicant. The District may require the applicant to post bond or otherwise ensure payment of such costs. The consultants shall be selected by mutual agreement of the District and the applicant after a call for proposals.

c. If a proposal is modified so that an EIS is no longer required, the responsible official shall refund any fees collected under (a) or (b) of this subsection which remain after incurred costs are paid.

3. Except when the District is the proponent of a proposal, the District may collect a reasonable fee from an applicant to cover the cost of meeting the public notice requirements of this resolution relating to the applicant's proposal.

4. The District shall not collect a fee for performing it's duties as a consulted agency.

5. The District may charge any person for copies of any document prepared under this resolution and for mailing the document, in a manner provided by Chapter 42.56 RCW.

SECTION 21. Supplemental Procedures. The responsible official is authorized to develop and promulgate such procedures as the responsible official deems appropriate for implementing the SEPA rules and this resolution. The responsible official shall provide

responses on behalf of the District when it is a consulted agency.

SECTION 22. Severability. If any provision of this resolution or its application to any person or circumstances is held invalid, the remainder of this resolution, or the provision to other persons or circumstances, shall not be affected.

SECTION 23. Forms. The District adopts the following forms and selections by reference:

WAC

| | |
|---|---|
| 197-11-960 | Environmental checklist. |
| 197-11-965 | Adoption notice. |
| 197-11-970 | Determination of nonsignificance (DNS). |
| 197-11-980 | Determination of significance and scoping notice (DS). |
| 197-11-985 | Notice of assumption of lead agency status. |
| 197-11-990 | Notice of action. |

KING COUNTY FLOOD CONTROL ZONE DISTRICT
KING COUNTY, WASHINGTON

_____

Reagan Dunn, Chair

ATTEST:

_____

Anne Noris, Clerk of the Board

**Attachments:** None

1200 King County Courthouse
516 Third Avenue
Seattle, WA 98104

# KING COUNTY

## Signature Report

**February 9, 2016**

**FCD Resolution**

**Proposed No.** FCD2016-05.1 **Sponsors**

A RESOLUTION relating to the Green River System-Wide Improvement Framework; directing the King County Director of Water and Land Resources to submit the Interim SWIF to the United States Army Corps of Engineers; providing for a Corridor Plan for the Lower Green River; establishing and appointing members of a Lower Green River Corridor Plan Advisory Committee; and authorizing a programmatic environmental impact statement SEPA process.

WHEREAS, in light of tribal correspondence regarding alleged violations of treaty rights and the Endangered Species Act ("ESA"), the King County Flood Control Zone District ("District") has consulted with staff for the Seattle District of the United States Army Corps of Engineers ("USACE") regarding the March 21, 2014, Interim Policy for Determining Eligibility Status, specifically USACE's policy not to conduct ESA Section 7 consultation for SWIF plan acceptance; and

WHEREAS, while that consultation is continuing, time is running short on completion of the Green River System-Wide Improvement Framework ("SWIF"), which necessitates planning for timely submittal of an interim SWIF that does not preclude other options for ESA compliance and achievement of broader objectives; and

WHEREAS, the executive committee has previously authorized the chair and vice-chair to request a time extension from the USACE for completion of a SWIF; and

WHEREAS, the extension request included a schedule for deliverables; and

WHEREAS, the executive committee submitted draft chapters of the Interim SWIF to the USACE for review and comment; and

WHEREAS, the submitted draft chapters have been revised to respond to USACE comments; and

WHEREAS, the District desires to move forward with a Lower Green River Corridor Plan similar to plans underway for the Cedar River, the Middle Fork Snoqualmie River, the South Fork Snoqualmie River and the Tolt River; and

WHEREAS, the broader objectives supported by stakeholders who participated as SWIF advisors can best be achieved through a long-range planning process that includes a SEPA programmatic environmental impact statement that can analyze cumulative impacts and reasonable alternatives for accomplishing project objectives of flood protection, economic vitality, salmon recovery, water quality, habitat restoration, recreation, housing, equity and social justice and other issues to be defined through the environmental impact statement scoping process, now therefore,

BE IT RESOLVED BY THE BOARD OF SUPERVISORS OF THE KING COUNTY FLOOD CONTROL ZONE DISTRICT:

SECTION 1. The District directs the director of King County water and land resources division to submit the System-wide Improvement Framework (SWIF) Interim Report February 2016, Attachment A to this resolution, to the United States Army Corps of Engineers for acceptance.

SECTION 2. The District establishes a Lower Green River Advisory Committee, and appoints members to the committee, as listed in Exhibit B to this

Resolution.

SECTION 3. The District directs the executive director to work with the director of water and land resources division to prepare a work plan and budget for a Lower Green River Corridor Plan.

SECTION 4. The District authorizes the executive director to initiate a request for proposal for a consultant to prepare a SEPA programmatic environmental impact statement for the Lower Green River Corridor Plan.

KING COUNTY FLOOD CONTROL ZONE DISTRICT
KING COUNTY, WASHINGTON

_____

Reagan Dunn, Chair

ATTEST:

_____

Anne Noris, Clerk of the Board

**Attachments:** None

# GREEN RIVER, KING COUNTY, WASHINGTON

# SYSTEM-WIDE IMPROVEMENT FRAMEWORK (SWIF)

# INTERIM REPORT

# FEBRUARY 2016

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# Chapter 1 Introduction

## 1.1 Green River System Wide Improvement Framework Interim Report Structure

This Green River SWIF Interim Report is comprised of six chapters:

- Chapter One provides an introduction to the Green River SWIF Interim Report, interagency collaboration that informed its preparation, and an overview of the Lower Green River PL 84-99 levee system.
- Chapter Two summarizes U.S. Army Corps of Engineers identified levee deficiencies needing corrective action to retain their PL 84-99 program eligibility. Corrective actions being proposed to resolve deficiencies are also summarized.
- Chapter Three provides an overview of the SWIF Interim Report Capital Plan, which when implemented will resolve those PL 84-99 deficiencies that cannot be corrected through routine maintenance and operations actions.
- Chapter Four presents a set of vegetation recommendations, intended to guide both routine vegetation management on existing PL 84-99 levee systems as well as future design of PL 84-99 shoreline capital projects.
- Chapter Five summarizes King County's proposed interim risk reduction measures that will be implemented as part of implementation, including structural and non-structural approaches that may be taken to reduce flood risks prior to capital project implementation.
- Chapter Six presents the Green River SWIF Interim Report funding and implementation strategy, including an implementation work plan and schedule to guide capital projects necessary to resolve PL 84-99 deficiencies, IRRM implementation and DAP maintenance actions.

## 1.2 What is the Green River System Wide Improvement Framework?

A System Wide Improvement Framework (SWIF Interim Report) is a U.S. Army Corps of Engineers sanctioned process to identify flood protection solutions for river systems with U.S. Army Corps of Engineers' PL 84-99 program levees that also contain multiple and often competing sets of federal mandates. A SWIF Interim Report is an integrated approach for local levee sponsors to resolve U.S. Army Corps of Engineers identified deficiencies in PL 84-99 levee systems, in support of retaining PL 84-99 program eligibility:

> *"A plan prepared by levee sponsors and approved by the USACE to implement system-wide improvements to a levee system (or multiple levee systems within a watershed) to address system-wide issues, including correction of unacceptable inspection items in a prioritized way to optimize flood reduction." (U.S. Army Corps of Engineers SWIF Interim Report Policy, 2011)*

The King County Flood Control District developed the Green River SWIF Interim Report, and convened an interagency collaboration and advisory process to inform preparation of the SWIF Interim Report. The Green River SWIF Interim Report implementation process will result in the timely resolution of USACE defined deficiencies, which affect program eligibility associated with levees enrolled in the USACE PL 84-99 program.

## 1.3 Interagency Collaboration

Many constituent interests provided input to preparation of the technical products that inform this SWIF Interim Report submittal. The 2012 King County Flood Control District *Letter of Intent* to the U.S. Army Corps of Engineers described a proposed approach to completing a SWIF for the Lower Green River that provided for "diverse and timely input" to the development of the Green River SWIF Interim Report. It further stated that the project's advisors would be comprised of local, state and federal agencies, Native American Tribes, business and environmental interests, and resource agencies.

The Flood Control District convened two advisory groups to inform the preparation of a Green River SWIF:

- Advisory Council. Members were at a leadership level in their respective organizations. This group was convened five times to receive project status briefings and provide policy input to the Flood Control District.
- Technical Advisory Committee. Members were convened 11 times to provide technical review of SWIF Interim Report work products, and provide technical and policy input for consideration by the Advisory Council.

Advisors were engaged throughout the preparation of the SWIF. All advisory meetings were open to the public and organized to provide timely input and recommendations to the project, in support of product development and Flood Control District decision-making at critical project junctures. Advisors represented the following organizations:

- King County Flood Control District
- King County
- Valley cities of Tukwila, Renton, Kent, and Auburn
- Muckleshoot Indian Tribe
- State agencies, including Puget Sound Partnership, the Department of Fish and Wildlife and the Department of Ecology
- Federal agencies, including U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration, and Federal Emergency Management Agency
- Water Resource Inventory Area (WRIA) 9
- Business community: Boeing, Washington REALTORS, Master Builders Association, and NAIOP Commercial Real Estate Development Association
- Environmental groups: The Nature Conservancy and American Rivers

Stakeholders, agencies, the tribe and other constituent interests will have ongoing opportunities to collaborate and provide input.

## 1.4 Green River System Wide Improvement Framework Project Area

The geographic scope of the Green River SWIF Interim Report includes a significant portion of the Green-Duwamish watershed. The upstream extent of the Green River SWIF Interim Report project area is the Howard Hanson Dam at river mile (RM) 64.5 and the downstream project extent is RM 5.5, the farthest downstream flood protection facility managed by the Flood Control District. The focal geography for this Green River SWIF Interim Report is the Lower Green River portion of the watershed, from RM 32 to RM 11, including the five PL 84-99 levee systems shown in **Figure 1.1**.

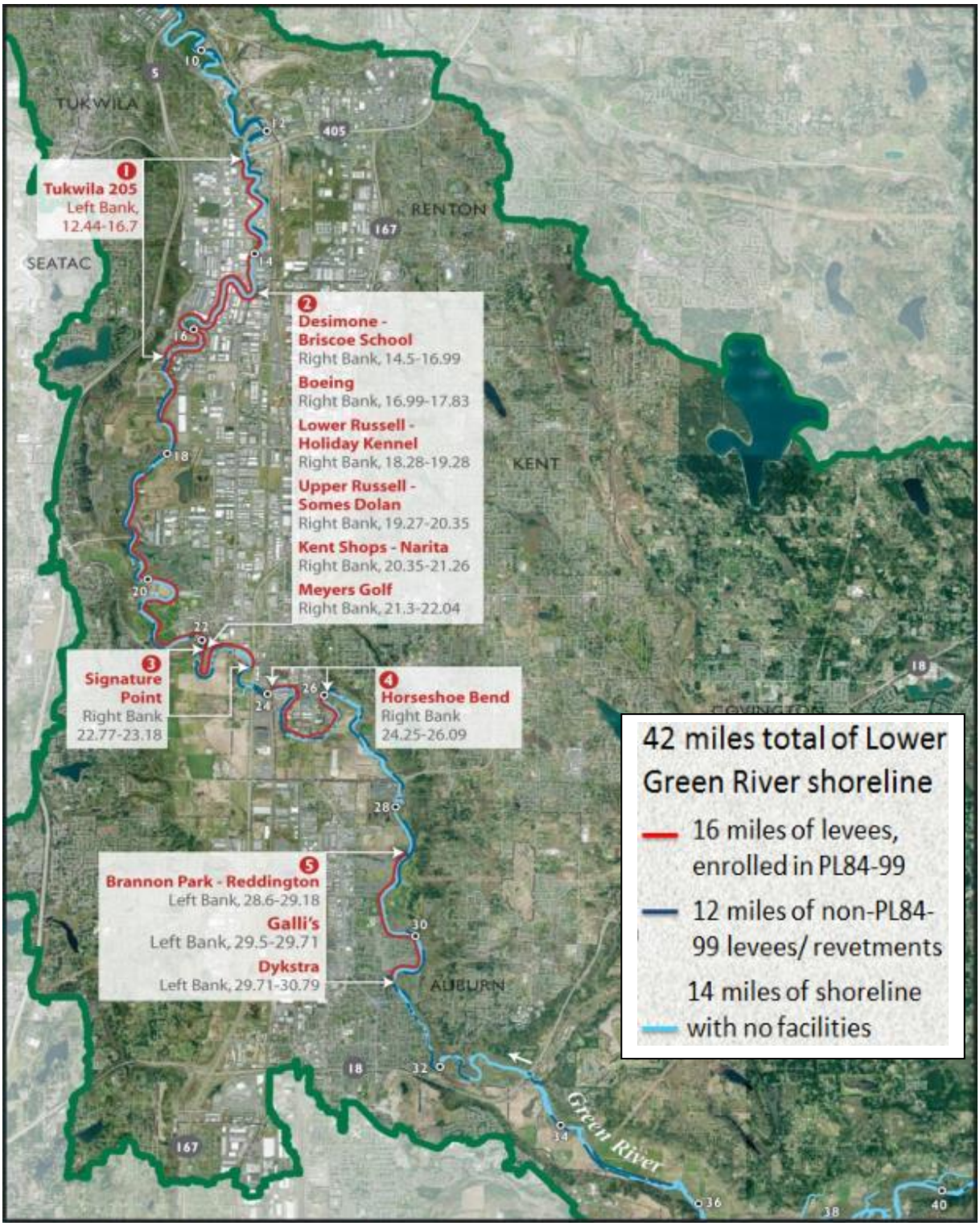



**Figure 1.1. Green River SWIF Interim Report Focal Geography (Lower Green River) and PL 84-99 Levee Systems**

## 1.5 Overview of Lower Green River PL 84-99 Levee Systems

In the Lower Green River there are approximately 28 miles of levees and revetments, of which 16 miles of levees are currently enrolled within the U.S. Army Corps of Engineers PL 84-99 program. King County sought enrollment of levees into the federal program in the early 1990s, due to the flood risk reduction role each levee plays and the importance of accessing federal funds in support of repairs to reduce flood risks, if they were to be damaged during a flood event.

This section of the report is a U.S. Army Corps of Engineers required SWIF Interim Report submittal element and describes the location and configuration of the system of levees currently enrolled in the PL 84-99 program. The federal PL 84-99 program enrolls levees that meet specific federal eligibility criteria; enrolled levees receive up to 80% of the cost of repairs for non-federal levees and 100% of the cost of repairs for federal levees, if they are damaged during a flood event. Each levee segment description includes a summary of its current condition including U.S. Army Corps defined deficiencies and other information. Though all deficiencies are important, the deficiency types that pose the greatest risk to Lower Green River levee integrity includes: slope stability and culvert deficiencies. Additional deficiency information and proposed corrective actions are further discussed in Chapter 2 of this report. Table **1.1** summarizes the 12 levee segments that comprise five levee systems, in the Lower Green that are active in the U.S. Army Corps of Engineers PL 84-99 program.

**Table 1.1 – Green River Levee Systems and Segments active within the PL 84-99 Program. Information taken from the National Levee Database System, maintained by the U.S. Army Corps of Engineers**

| Levee System Name | Levee Segment Name | National Levee Database System ID | National Levee Database Segment ID | Segment Length (miles) |
|---|---|---|---|---|
| **Tukwila 205 (#1)** | Tukwila | 5505000020 | 5504000020 | 4.1786 |
| **Lower Green Right Bank (#2)** | Desimone – Briscoe School | 5505000043 | 5504000075 | 2.2024 |
| **Lower Green Right Bank (#2)** | Boeing | 5505000043 | 5504000045 | 0.8453 |
| **Lower Green Right Bank (#2)** | Lower Russell Road-Holiday Kennel | 5505000158 | 5504000161 | 0.9427 |
| **Lower Green Right Bank (#2)** | Upper Russell Road Somes-Dolan | 5505000158 | 5504000279 | 1.0287 |
| **Lower Green Right Bank (#2)** | Kent Shops-Narita | 5505000158 | 5504000137 | 0.9325 |
| **Lower Green Right Bank (#2)** | Meyers Golf | 5505000158 | 5504000179 | 0.76 |
| **Signature Point (#3)** | Signature Point | 5505000068 | 5504000071 | 1.0795 |
| **Horseshoe Bend (#4)** | Horseshoe Bend | 5505000009 | 5504000009 | 1.8452 |
| **Galli/ Dykstra Reddington (#5)** | Reddington | 5505000078 | 5504000236 | 0.9043 |
| **Galli/ Dykstra Reddington (#5)** | Galli | 5505000078 | 5504000102 | 0.2315 |
| **Galli/ Dykstra Reddington (#5)** | Dykstra | 5505000078 | 5504000081 | 1.0514 |

A brief description of each PL 84-99 levee system and its component levee segments is provided below. Please refer to **Figure 1.1** for the mapped location of each PL 84-99 levee system.

### 1.5.1 Levee System #1

#### *Tukwila 205*

The Tukwila 205 levee is located on the left bank of the Lower Green River between RM 12.45 and RM 16.72 within Tukwila. The existing PL84-99 levee is in close proximity to privately owned buildings, parking lots and other land uses, including: commercial/industrial, public facilities, religious buildings, and utilities. Recreational resources in the vicinity of the levees include the Green River Regional Trail and Bicentennial Park.

The Tukwila 205 levee was damaged and repaired in 1990, 1992, 1995, 1996, 1997, 2003, 2005, 2008, and 2009. Levee overtopping is expected to occur at a flooding stage of about 18,800 cubic feet per second, or approximately a 500-year flood event. Though the current levee reduces flood risk up to approximately a 500 year level of protection, there is little to no freeboard, or extra height above the design water surface, as typically incorporated into engineering design standards. The U.S. Army Corps of Engineers (USACE) inspections have revealed the following levee deficiency types that require correction, to maintain the levee's eligibility for the PL84-99 program: encroachments, erosion, scour, animal burrows, slope stability, depressions/rutting, sliding and obstructions. The proposed deficiency action plan for this levee would correct these deficiencies, including slope stability deficiencies at five locations, in three areas, along the levee that do not meet the USACE PL84-99 program eligibility requirements. The city of Tukwila is currently completing technical studies in support of getting the Tukwila 205 levee certified and ultimately accredited by FEMA. It is likely that certification studies will be completed in 2016 and contain capital project recommendations that may be aligned with SWIF Interim Report implementation over time.

Aquatic habitat in this area is degraded. Riparian habitat is degraded, of low quality and consists predominantly of impervious surfaces, non-native shrubs (mostly invasive blackberry), grasses, some trees, and bare earth. There is less than 10% tree cover which is concentrated in one patch adjacent to a stormwater pond located at RM 13.9. According to the Muckleshoot Tribe's Lower Green River solar radiation priorities mapping (2013), approximately 50% of the levee system's shoreline is considered a high priority for achieving additional shoreline shade trees, as it is a west bank with several southern exposures around its bends.

## 1.5.2 Levee System #2

### *Desimone Briscoe School*

The Briscoe-Desimone levee system is located within the jurisdictions of Tukwila and Kent on the right bank of the Lower Green River between RM 14.5 and RM 17.0. Existing PL84-99 levees and floodwalls are located close to privately owned buildings and parking lots and they protect commercial, industrial, and public land uses. Recreational resources associated with this project area include the Green River Regional Trail and Briscoe Park.

Levee overtopping in the Briscoe-Desimone project area can be expected to occur when flows exceed 15,100 cubic feet per second (cfs) (an approximately 350-year flood event. Flood events in 1995, 1996 and 2006 damaged the levees; three repair projects were completed in 1998, 1999, and 2002 and an additional repair was done in 2009. The Flood Control District and the City of Kent is currently completing construction of four floodwall segments within the project area, totaling 0.85 miles (4,500 feet) in length and designed to a 500-year level of protection (LOP)/18,800 cubic feet per second (cfs) + 3 feet of freeboard standard to enable certification of the levees and floodwalls.

The U.S. Army Corps of Engineers (USASE) PL84-99 program eligibility levee inspections identified the following categories of unresolved levee deficiencies including: encroachments, animal burrows, depressions/rutting, erosion, cracking, slope stability and settlement. The slope stability deficiency will be resolved through a maintenance project that is anticipated to be completed by 2016.

Aquatic habitat in this reach is degraded. Riparian habitat is degraded and consists mainly of grasses, shrubs (mostly invasive blackberry) and some trees. The majority of the shoreline (81%) is identified as high priority for achieving additional shading to the main channel, per the Muckleshoot Indian Tribe Lower Green River Solar Radiation Priorities Mapping Study (2013).

### *Boeing*

The Boeing levee continues along the right bank between RM 16.99 and RM 17.83. Its geometry is similar to the Desimone Briscoe School levee, typically 5 to 10 feet in height, and 10 to 20 feet wide at the crest. The levee is setback approximately 125 feet from the Green River. Riverside slopes are moderately inclined at about 2H:1V.

The levee embankment soils are similar in composition to the underlying alluvium, consisting of loose to medium dense silty sand with gravel and sandy silt with gravel. The alluvial soils typically consist of medium dense sand with variable silt content with occasional layers of soft to medium stiff silt and organic silt. Groundwater levels were measured within the Boeing reach at about 18 to 19 feet below the ground surface in February 2011.

Recent levee improvements within the Boeing levee include several localized bioengineered repairs of pronounced embankment slumps completed in the 1990s, the setback of approximately 4000 feet of the levee crest in 2000, and construction of a secondary levee and floodwall at its downstream end in 2013.

### *Lower Russell – Holiday Kennel*

The Lower Russell and Holiday Kennel levees are located within the City of Kent on the right bank of the Lower Green River, between RM 17.85 and RM 19.25. The existing PL 84-99 levees and revetments protect commercial/industrial and residential land uses in Kent, Renton and Tukwila. Van Doren's Park, the Green River Natural Resources Area and the Green River Regional Trail are located in the vicinity of this project area.

Levee overtopping in this project area can be expected to occur when flows at the Auburn gage are between 15,100 and 18,800 cubic feet per second (cfs) (an approximately 350- to 500-year event). A portion of the Lower Russell levee was damaged in 1995/96 and repaired in 1997-98 in the vicinity of RMs 17.9, 18.7, 18.9 and 19.2. In addition, there has been significant scour and damage to the levee toe and embankment at RM 18.6 between 2013 and 2015. USACE PL 84-99 eligibility inspections identified the following eligibility categories of deficiencies: encroachments, animal burrows, erosion, debris, slope stability, and settling. The proposed capital project will correct these known deficiencies, including the unacceptable slope stability deficiency at river mile 18.6. The Lower Russell Project is currently in a preliminary design phase and will correct PL 84-99 slope deficiencies while also achieving a 500-year level of flood protection, habitat restoration and recreational enhancements.

Aquatic habitat in this area is degraded. Riparian habitat is degraded and consists predominantly of grasses, shrubs, and some narrow rows of trees. Approximately 82% of the shoreline is considered high priority for increasing shade, per the Muckleshoot Tribes Solar Radiation Priorities Mapping Study (2013).

### *Upper Russell Somes Dolan*

The Upper Russell levee is located within the City of Kent on the right bank of the Lower Green River, between RM 19.28 and RM 20.39. This PL 84-99 levee protects residential land uses, including the Lakes Condominiums, and other commercial/industrial land uses in Kent east of the river. The Green River Regional Trail is located along this project area.

Levee overtopping in this area can be expected to occur when flows at the Auburn gage are between 15,100 and 18,800 cubic feet per second (cfs) (an approximately 350- to 500-year event). A portion of the Upper Russell levee was damaged in 1995/96 and repaired in 1998 in the vicinity of RM 20.3. USACE PL 84-99 eligibility inspections identified the following eligibility categories of deficiencies: encroachments, animal burrows and one slope stability location.

Kent constructed a 1200-foot long secondary levee on the north reach of Upper Russell, designed to 15,300 cfs plus three feet of freeboard in 2013, and realigned the James St / Russell Rd intersection and raised the levee at the south end in 2014 and is currently constructing a south reach secondary levee north of the James/Russell intersection and Lakes community (approximately 1600 feet long), designed to 18,800 cfs, plus three feet of freeboard. These capital projects will enable certification and accreditation of the levee.

Aquatic habitat in this area is degraded. Riparian habitat is degraded and consists predominantly of grasses, shrubs, and some narrow rows of trees, with the exception of more dense trees at north of reach at Russell Woods adjacent to 218$^{th}$ Street. Approximately 30% of the shoreline is considered high priority for increasing shade, per the Muckleshoot Tribes Solar Radiation Priorities Mapping Study (2013).

### *Kent Shops-Narita and Meyers Golf*

The Kent Shops- Narita and Meyer's Golf levees are located within Kent on the right bank of the Lower Green River between RM 20.39 and RM 22.04. These PL84-99 levees protect residential, commercial, and public land uses. The current shoreline has a combination of revetments (Hawley and Signature Pointe) and flood protection levees (County Road #8, Myers Golf, Okimoto, Pipeline, and Narita 1&2). Damages/repairs to the levee within this project area were reported in 1993, 1996, 1997, 1999, 2002, 2003, and 2008 according to King County records.

Levee overtopping in this area can be expected to occur at flows exceeding 15,100 cfs. Currently unresolved individual deficiencies include unwanted vegetation growth, encroachment, animal burrows and erosion.

Aquatic habitat in the mainstem river mostly consists of glides and runs, with two pools located near RM 20.8 and 21.2, and one riffle near RM 21.2. Riparian habitat consists mainly of grass and impervious areas, with lesser areas of invasive shrubs and some trees. There are placed logs along the right bank of the river from RM 20.5 to 21.05 and from RM 21.554 to 21.82. The majority of the left bank in this reach is considered high or critical priority for shading because of the southern exposure and the very limited presence of trees, per the Muckleshoot Tribes Solar Radiation Priorities Mapping Study (2013). This levee system is not located within a spawning reach.

## 1.5.3 Levee System #3

### *Signature Point, County Road No. 8*

Upstream of the Meyers Golf levee, the Signature Point levee extends on the right bank, between RM 22.77 and RM 23.18, within the city of Kent. This levee system protects multiple land uses, including residential apartment complexes, recreational areas (Riverbend Golf Course, Green River Trail and Riverview Park) and a few commercial businesses. This levee is less than five feet in height, and the crest width is greater than 20 feet. Riverside slopes are locally flatter than 2H:1V. In 1996-97, pronounced slumping of hundreds of feet of the levee embankment slopes were improved with large rock toe structures, log flow deflectors, and bioengineered reconstruction of the embankment slopes.

Approximately 75% of the shoreline in the vicinity of this levee system is considered high or intermediate priority for increasing shade, per the Muckleshoot Tribes Solar Radiation Priorities Study (2013).

## 1.5.4 Levee System #4

### *Horseshoe Bend*

The Horseshoe Bend levee is located within the City of Kent on the right bank of the Lower Green River, between RM 24.05 and RM 26.14. This PL84-99 levee protects commercial, industrial, residential and recreational land uses. Most of the levee (1.9 miles) is part of the Horseshoe Bend Federal levee that was raised and improved by the U.S. Army Corps of Engineers (USACE) in 1996. In 2012-13, Kent constructed secondary containment structures (flood walls and berms), designed to 12,000 cfs plus 3 feet of freeboard, to advance the city's certification and accreditation goals. The Green River Regional Trail is located atop the levee throughout most of this project area.

Levee overtopping in this area can be expected to occur at flows exceeding 15,100 cubic feet per second (cfs) (an approximately 350-year event). Portions of the existing Horseshoe Bend levee were damaged/repaired during the following years: 1991, 1994, 1996, 2003, 2006, and 2009. USACE PL84-99 eligibility inspections identified the following categories of deficiencies: encroachments, debris, depressions/rutting, erosion, slope stability, unwanted vegetation, and cracking. There are four slope stability problem areas noted with slopes between 1H:1V to 1.7H:1V near RMs 24.3, 25.5, 25.8, and 26.1. The proposed Deficiency Action Plan for this levee provides recommended corrective actions, including completion of capital projects for three shoreline segments, to resolve the USACE identified slope stability deficiencies.

Aquatic habitat in this area is less degraded, relative to downstream Lower Green River locations, and Chinook salmon have been documented spawning from RM 24.5 and further upstream. Riparian habitat is degraded and consists predominantly of grasses, shrubs, and some narrow rows of trees. Approximately 35% of the shoreline is considered high priority for increasing shade, per the Muckleshoot Tribes Solar Radiation Priorities Study (2013).

## 1.5.5 Levee System #5

### *Reddington*

The Reddington levee extends between RM 28.6 and RM 29.5 along the left bank. The levee was reconstructed and set back from the Green River, and extended downstream in 2013-14. Levee heights in this area are typically less than five feet, but with some areas between five and ten feet in height. The levee crest width was reconstructed to a width of 20 feet, and the reconstructed riverside slopes typically vary from 2.5H:1V to 3H:1V. There are no deficiencies identified for the Reddington levee. Habitat features associated with the Reddington levee set back project include rock barbs and engineered log jams in support of fish rearing and refuge habitat, and upland riparian plantings of native trees and shrubs. Approximately 40% of the shoreline is considered high priority for increasing shade, per the Muckleshoot Tribes Solar Radiation Priorities Study (2013).

### *Galli's Dykstra*

The Galli's/Dykstra levees are located within Auburn on the left bank of the Lower Green River, between RM 29.48 and 30.79. These PL 84-99 levees protect commercial and residential land uses and are adjacent to primarily single and some multi-family residential properties; there are a total of 84 residential structures, immediately adjacent to the existing levee.

Levees in this area are subject to overtopping at 15,100 cubic feet per second (cfs) (approximately a 350-year flood event). Repairs to the levees were completed in 1992, 1994, and 2008, and are planned in 2016 under the PL 84-99 program. U.S. Army Corps of Engineers (USACE) inspections identified the following categories of unresolved PL84-99 program eligibility deficiencies: animal burrows, insufficient riprap protection at two locations, encroachments, and issues related to the interior drainage culverts.

This area contains relatively high quality salmonid habitat; it is an active spawning reach for salmonids and aquatic habitat in this project area is more diverse than the majority of the Lower Green River. Aquatic habitat types include glide and riffle habitats, with one large mid-river island near RM 30.1. There is minimal riparian shade tree cover in this project area and the majority (71%) of the shoreline is identified as a high priority location, per the Muckleshoot Indian Tribe's solar radiation priorities GIS model (2013).

# Chapter 2 PL 84-99 Deficiency Action Plan

The Green River Levee Deficiency Action Plan (DAP) is a submittal to the U.S. Army Corps of Engineers (USACE) as part of the Green River System-wide Improvement Framework Interim Report. It addresses the deficiencies identified by the USACE for the twelve levee segments in the Lower Green River system (Figure 1.1). This chapter summarizes the Deficiency Action Plan, including the current USACE defined deficiencies associated with Lower Green River levees enrolled within the PL 84-99 program and King County Flood Control District's (District) proposed corrective actions.

The federal PL 84-99 program, administered by the USACE, enrolls levees that meet specific federal eligibility criteria. Benefits of this federal program are reduced flood risk and that enrolled levees may receive post-disaster, federal rehabilitation assistance (100% federal funding for federal levees and 80% federal funding for local levees). The King County Flood Control District is the local levee sponsor responsible for maintaining the eligibility of 16 miles of Lower Green River levees enrolled within the USACE's Rehabilitation and Inspection Program (PL 84-99). The USACE conducts periodic and continuing levee inspections to produce a rating that is based on the USACE's levee inspection checklist, which includes 125 operational and maintenance criteria associated with levee embankments, floodwalls, and interior drainage. The USACE rates each PL 84-99 levee segment as *Acceptable*, *Minimally Acceptable*, or *Unacceptable* to determine eligibility status (Table **2.1**).

Table 2.1. USACE Inspection Rating Categories for PL 84-99 Enrolled Levees

| USACE Rating Categories | Rating Definitions |
|---|---|
| **Acceptable (A)** | • All inspection items are rated as Acceptable and no work is required except typical Operation and Maintenance. |
| **Minimally Acceptable (M)** | • Deficient conditions exist which should be improved by the levee sponsor/owner.<br>• One or more inspection items are rated as Minimally Acceptable or one or more items are rated as Unacceptable and an engineering determination concludes that the unacceptable inspection items would not prevent the segment/system from performing as intended during the next flood event. |
| **Unacceptable (U)** | • A condition exists which requires immediate corrective action to be taken by the sponsor/owner before the levee is eligible for inclusion into the PL 84-99 Rehabilitation and Inspection Program.<br>• One or more inspection items are rated as Unacceptable and would prevent the segment/system from performing as intended, or a serious deficiency noted in past inspections (previous Unacceptable items in a Minimally Acceptable overall rating) has not been corrected within the established timeframe, not to exceed two years. |

In the Lower Green River system of PL 84-99 levees, there are currently three unacceptable rated levees, eight minimally acceptable rated levees and one acceptable rated levee (Table 2.2). Through implementation of the SWIF Interim Report's Deficiency Action Plan, the District intends to achieve acceptable ratings, for all PL 84-99 enrolled levees in the Lower Green River.

Table 2.2. Green River Levee Systems and Segments in the PL 84-99 Program

| USACE Levee Segment Name | Segment Length (miles) | Ratings [b] | Status |
|---|---|---|---|
| **Tukwila 205 (Federal)** | 4.1786 | M | Eligible [a] |
| **Desimone-Briscoe School** | 2.2024 | U | Eligible [a] |
| **Boeing** | 0.8453 | M | Eligible[a] |
| **Lower Russell Road – Holiday Kennel** | 0.9427 | U | Eligible[a] |
| **Upper Russell Road – Somes-Dolan** | 1.0287 | U | Eligible[a] |
| **Kent Shops – Narita** | 0.9325 | M | Eligible[a] |
| **Meyers Golf** | 0.76 | M | Eligible[a] |
| **Signature Point (County Road No. 8)** | 1.0795 | M | Eligible[a] |
| **Horseshoe Bend (Federal)** | 1.8452 | M | Eligible[a] |
| **Reddington** | 0.9043 | A | Eligible |
| **Galli** | 0.2315 | M | Eligible[a] |
| **Dykstra** | 1.0514 | M | Eligible[a] |

Eligible[a] = Eligibility status of twelve levee segments currently enrolled within the USACE PL 84-99 program. Levee eligibility is retained during development of the Green River Interim SWIF Report..
Ratings [b] = Reflects April 2014 USACE inspection ratings.

While the District was preparing the Green River System Wide Improvement Framework, the USACE completed two continuing inspections of the Lower Green River PL 84-99 levees (June 2013 and April 2014) and the resulting deficiency database serves as a primary information source for the Deficiency Action Plan.

A second important source of information is the *Interim Policy for Determining Eligibility Status of Flood Risk Management Projects to Rehabilitation Program, Pursuant to PL 84-99* (2014). This interim policy guidance established a reduced number of eligibility criteria to maintain PL 84-99 levee enrollment. The most important effect of the 2014 Interim Policy Guidance upon the Lower Green River levee system is that though USACE will continue to inspect and rate vegetation on levees, to determine compliance with federal vegetation standards, but these inspection ratings will not affect PL 84-99 eligibility determinations. If existing vegetation does not comply with federal standards, the USACE will identify it as a 'deficiency,' but vegetation deficiencies will not be incorporated into the assignment of ratings for each levee segment. Local levee sponsors are responsible for managing vegetation to ensure levee integrity and to support facility access for operations and maintenance, inspections, monitoring and flood fighting. The Vegetation Plan (Chapter 4 of this report) details how to manage vegetation in the vicinity of levees and floodwalls.

Most USACE defined levee deficiencies will be resolved through ongoing maintenance, operations and technical assessments. A subset of current deficiencies, related to slope stability (over-steepened slopes), will be resolved through a capital project, as further described in Chapter 3 of this report.

The Deficiency Action Plan provides a road map for how remaining deficiencies will be resolved by the District, through implementation of the Green River SWIF Interim Report. King County on behalf of the District continued to take corrective actions and resolve deficiencies, while preparing the SWIF Interim Report. Actions taken in 2013-2014 resulted in significant improvements in USACE's rating and status of Lower Green River levees. During this period, completed corrective actions resulted in improved ratings for three levee segments (Meyers Golf, Signature Point, and Dykstra) from *Unacceptable* to *Minimally*

*Acceptable* (USACE Levee Inspection System Summary Report July, 2014). Three levee segments are still rated *Unacceptable*: Desimone-Briscoe School; Lower Russell Road-Holiday Kennel; and Upper Russell Road Somes-Dolan. Most of the USACE defined deficiencies for these three levees will be corrected by ongoing capital projects or projects funded through the existing 6-year CIP.

## 2.1 Summary of Lower Green River Levee Deficiencies

This section of Chapter 2 provides a summary of deficiencies for the Lower Green River PL 84-99 levee systems. The District completed extensive mowing, brushing, and invasive vegetation removal in early 2014 in advance of continuing inspections for the PL 84-99 levees in April 2014. The USACE identified 356 levee deficiencies and a database is maintained to track deficiencies, corrective actions and work planning needed to resolve each deficiency.

An overview of all deficiencies by levee inspection category, for eleven PL 84-99 Lower Green River levee segments, is included in Table **2.3** below. The Reddington Levee is not included in this summary of deficiencies as it was reconstructed in 2013-14 and received an acceptable levee rating from the USACE.

Two categories of deficiencies comprised 154 of the 356 deficiencies: Unwanted Vegetation Growth (115 sites) and Animal Burrows (39 sites). The next highest number of deficiency categories were Encroachments (61 sites) and Other-Culverts (56 sites). There were 35 internal drainage outfalls to the Green River identified within the levee system and forty-four deficiencies were identified associated with these outfalls.

Table 2.3. Lower Green River Levee Systems Inspection Ratings – total for all 11 levees

| Levee Inspection Category | Unacceptable Rating | Minimally Acceptable Rating | Acceptable Rating | Total # |
|---|---|---|---|---|
| Unwanted Vegetation Growth | 84 | 28 | 3 | 115 |
| Encroachments | 8 | 40 | 13 | 61 |
| Other-Culverts | 31 | 8 | 17 | 56 |
| Animal burrows | 1 | 38 | 0 | 39 |
| Slope Stability | 1 | 10 | 22 | 33 |
| Erosion | 2 | 12 | 3 | 17 |
| Depression | 1 | 8 | 0 | 9 |
| Excavation | 0 | 3 | 1 | 4 |
| Breaks | 0 | 1 | 4 | 5 |
| Debris | 0 | 3 | 0 | 3 |
| Cracking | 0 | 1 | 0 | 1 |
| Sediment | 2 | 0 | 0 | 2 |
| Settling | 0 | 1 | 1 | 2 |
| Seepage | 0 | 1 | 1 | 2 |
| Scour | 1 | 0 | 0 | 1 |
| Structure | 0 | 1 | 0 | 1 |
| Obstruction | 1 | 2 | 2 | 5 |
| **Total** | **132** | **157** | **67** | **356** |

**Note:** 'Acceptable' deficiency ratings, by the USACE, do not require specific correction action but may warrant some ongoing monitoring or routine maintenance (e.g., mowing), thus are included in the totals.

## 2.2 Deficiency Action Plan

This section of Chapter 2 summarizes how and when the District proposes to resolve USACE defined PL 84-99 deficiencies on the Lower Green River levees. The Deficiency Action Plan will guide the activities needed to correct deficiencies, including anticipated milestones and also inform future USACE levee inspections and programmatic reporting requirements.

### 2.2.1 Phasing and Sequencing of Corrective Actions

All deficiencies on the Lower Green River PL 84-99 levees will be resolved by corrective actions that fall into one or more of the following phasing and sequencing categories:

1. **Near term actions** to be completed in 2016-2017
2. **Mid-term actions** to be completed concurrent with the District's 6 year CIP (2016-2021)
3. **Long-term actions** to be completed after 2021
4. **Programmatic actions** that are ongoing
5. **Monitoring actions** that are ongoing

To generate a phased and sequenced approach to resolving current levee deficiencies, each deficiency was evaluated and prioritized using a "worst-first" approach, paired with consideration for what additional work could be completed due to opportunity and available resources. Two categories of deficiencies, slope stability and culverts, present the highest risks to the integrity of the Lower Green River levee systems. Accordingly, corrective actions are prioritized for these deficiency types, using a worst-first approach.

Corrective actions prioritized to be completed in the near and mid-term (during the 2016-2021 time period) reflect those deficiencies that are contributing to an 'Unacceptable' or 'Minimally Acceptable' levee rating. In some cases, these actions will result in a deficiency being resolved. In other cases, the near-term action involves completing additional assessments to better understand the stated deficiency, the risk it poses and ultimately to inform the development of future corrective actions. Longer-term corrective actions (beyond the 2021 timeframe) are proposed to resolve slope stability deficiencies that require a capital action, and that may also be designed to achieve a higher level of flood protection and meet certification requirements. Finally, some deficiencies will be resolved by implementation of the Vegetation Plan, Animal Burrow Management Plan, and ongoing monitoring of levee conditions.

In 2016-17, near-term actions will focus on remaining culvert and pipe repairs, stump removals, site assessments, and encroachments (e.g., solid fences that limit access or impede visual inspection). Mid-term actions include site assessments, implementation of the Vegetation Management Plan, and capital projects that are part of current Flood Control District 6-year CIP (2016-2021). Long-term actions are capital projects that are expected beyond the current 6-year CIP (approximately 2021 – 2026, or beyond. Long-term actions include capital projects that correct current slope stability deficiencies (current riverward levee slopes that are over-steepened and range between 1.25:1 and 1.7:1) on PL 84-99 levee segments.

Some deficiencies will be corrected through ongoing programmatic actions, per implementation of the Vegetation Management Plan and the Animal Burrow Management Program. Some deficiencies do not pose an active threat to levee performance and the corrective action is 'monitor'. These ongoing observations will determine if additional actions might be needed in the future. Finally, there is a category called "no further action required" that indicates the deficiency is acceptable, the deficiency was corrected since the USACE inspection (e.g., maintained by the city or private owner), or the deficiency was assessed by a professional engineer and there was a determination that there is "no discerned risk to levee performance." This finding will be confirmed with USACE in advance of and during the next continuing eligibility inspections. Table 2.4 shows the type, timing, and number of corrective actions by categories, and includes specific examples.

Table 2.4. Timing of Proposed Corrective Actions for Lower Green PL 84-99 Levees

| Type of Corrective Action | Timing | # of deficiencies to be corrected | Notes |
|---|---|---|---|
| **2014 Actions Completed** | 2014-2015 | 31 | Completed actions addressed the following deficiency types: culvert/pipe (CCTV) inspections, repaired flap gates, annual mowing of invasive vegetation and grasses, 2014 capital repairs at Briscoe/Desimone floodwalls and Reddington levee |
| **Near-term Actions** | 2016-2017 | 71 | Examples of near-term corrective actions, (note that this list is not all inclusive):<br>(1) outfall/pipe repairs<br>(2) stump removal<br>(3) flap gates<br>(4) CCTV of levee pipe/flapgate penetrations<br>(5) Re-vegetation of denuded, erosion prone slopes<br>(6) site surveys and site assessments<br>(7) fence removals<br>(8) USACE Capital Project at Desimone levee |
| **Mid-term Actions** | 2016-2021 | 15 | Includes two types of corrective actions:<br>(1) Site assessments to address deficiencies associated with slope stability, penetrations – drainage systems, and timber pilings. Site assessments will produce corrective action recommendations that will be included in future updates to this DAP.<br>(2) Capital plan implementation to resolve deficiencies at Lower Russell and Upper Russell, and possible Horseshoe Bend early action Capital Project. |
| **Long-term Actions** | 2021 – 2026 (next 6-year CIP) | 8 | Includes: SWIF Interim Report Capital Plan implementation for 5-6 capital projects. Slope stability is the primary deficiency type to be resolved through capital project implementation at the following PL 84-99 levees: Tukwila 205 and Horseshoe Bend. |
| **Programmatic Actions: Vegetation** | ongoing | 115 | Includes: SWIF Interim Report Vegetation Plan Implementation on current PL 84-99 levees, per Chapter 5 of the SWIF Interim Report Veg Plan. Removal of invasive species and thinning and/or removal of trees/shrubs on PL 84-99 levees, as informed by hazard tree inspections to be completed by KC FCD |
| **Programmatic Actions: Animal Burrows** | ongoing | 39 | Includes: annual inspection of animal burrows; pilot program. |
| **Monitoring Actions:** | ongoing | 24 | Ongoing monitoring of minor erosion, sloughing, rip rap, scouring, slope stability (minor), private drainage, encroachments, and vegetation. Some |

| Type of Corrective Action | Timing | # of deficiencies to be corrected | Notes |
|---|---|---|---|
| | | | are 'acceptable' deficiencies. |
| **No further action required** | N/A | 53 | Examples include: Some are 'acceptable' deficiencies; KC FCD annual mowing in support of inspections, etc. |
| **Total** | | 356 | |

### 2.2.2 PL 84-99 Deficiency Corrective Action Types

This section of Chapter 2 provides a description of corrective action types that the District will implement to resolve deficiencies. The Lower Green River Deficiency Database identifies specific corrective action types for each levee deficiency.

**Site Assessments and Site Surveys**

A total of 11 site assessments are proposed to evaluate slope stability deficiencies and a few culvert-pipe outfall items. Some will be carried out by the District and others by the cities. Licensed engineers complete site assessments to further evaluate deficiencies, for the purpose of better understanding the risks associated with these deficiencies as well as generating informed corrective action recommendations. Slope stability problems (typically oversteepened slopes of 1.2H:1V to 1.7H:1V), scour, erosion, and levee deformations were identified as deficiencies warrant additional field survey and geotechnical evaluation. For the Tukwila 205 levee, these will also be coordinated with Tukwila's ongoing certification assessment.

Site assessments will be completed for areas that range from approximately 800 – 2,500 feet in facility length and some site assessments will involve: completion of site surveys; analysis of existing borings; soil sampling and testing; and slope stability analyses. KC FCD will complete site assessments for portions of: Tukwila 205; Desimone-Briscoe School; and Horseshoe Bend. Four site assessment areas contain pipes, culverts and other internal drainage penetrations through a levee and are a high priority to complete due to potential risks to levee integrity. The other eight site assessment areas contain deficiencies related to slope stability and existing over-steepened riverward slopes.

Site surveys are completed when a licensed engineer determines that additional measurements and professional land surveys are needed to confirm whether erosion, slide, slope stability or depression deficiencies are located within the levee prism. In the near-term, site surveys are proposed for three locations on portions of: Desimone/Briscoe School and Meyers Golf.

**Culverts, outflows, and flood closure devices**

A total of 13-15 culverts, outflows and flood closure devices are proposed to be assessed, evaluated and corrected (2 in Tukwila, 6-9 in Kent, and 5 in Auburn). Levees that are penetrated by culverts and outflows require coordination with local municipalities and private owners, to conduct inspections and assessments of the pipe, backwater controls and outfalls. For the majority of drainage outfalls, the municipality conducts the pipe inspection, and a professional civil engineer visually inspects the section penetrating the levee, including the first manhole upstream of the river outfall. Closed circuit TV (CCTV) assessment of all drainage outflow pipes and culverts, as well as an inspection of flood closures (e.g.,

flap gates, tide flex) are evaluated by a licensed engineer to recommend a course of action: monitor, repair, remove or replace.

**Fence and/or gate removals**

A total of 26 fence encroachment or obstruction issues are included in the deficiencies list, four of which are identified as unacceptable (three on Tukwila 205 and one at Lower Russell). Several fence and/or gate related encroachment deficiencies are being corrected by removal of fencing slats (at Tukwila 205), one fence is being removed (Horseshoe Bend) and several others will be further evaluated. The Lower Green River levee system contains numerous fence and gate encroachments on the levee landward slope or within the 15-foot inspection zone located at the landward toe of the levee. All such encroachments are assessed to determine if an easement exists, as well as to verify the function of the fence or gate in question. Most fences are cyclone fencing and many contain wood slats that obstruct visual inspection of the levee and a portion of the landward slope. A subset of these fences and gates were permitted by local jurisdictions, while others were constructed without permits. Work is underway with cities and property owners to resolve these deficiencies in a manner that results in clear sight lines of the levee slope and inspection zone. Some corrective actions may include removal of fence slats, moving fences and gates to a different location, or obtaining legal access for those fences that were legally permitted so that levee backslopes and inspection zones can be observed during flood events for seepage or other failures.

**Vegetation Plan implementation**

King County manages vegetation in the vicinity of its PL 84-99 enrolled levees to support levee inspections, remove hazard trees and to steward riparian vegetative communities in locations that do not pose a risk to the inner levee core prism. This approach to vegetation maintenance practices is consistent with the principles outlined within the *Interim Policy for Determining Eligibility Status of Flood Risk Management Projects to Rehabilitation Program, Pursuant to PL 84-99* (2014). An important consideration for vegetation management is to ensure that vegetation does not impede inspection yet supports habitat and water temperature goals. The Vegetation Plan, summarized in Chapter 4 of this report, provides vegetation management guidance for current and future PL 84-99 levees and floodwalls.

Removal of stumps located within the levee prism is a priority. Nearly 500 trees were cut in 2008-9 to comply with PL 84-99 requirements and stump removal was initiated in 2014 and will continue in the near-term, through 2016. This corrective action includes the removal of stumps and roots that exceed 1/2 inch in size. Levee slopes will be regraded and reseeded, and levee crests paved, as appropriate.

**Slope Stability (Over Steepened Slopes) to be Corrected through the SWIF Interim Report Capital Plan**

A total of 11 slope stability deficiencies (10 minimally acceptable and 1 unacceptable at Lower Russell) are included in the deficiencies list and are planned for correction over time. Longer-term corrective actions (beyond the 2021 timeframe) are proposed to resolve slope stability deficiencies that require a capital action, and that may also be designed to achieve a higher level of flood protection and meet certification requirements. In these cases, the deficiencies will be resolved through implementation of the SWIF Interim Report Capital Plan. In the near-term, slope deficiencies will be resolved through completion of the Briscoe maintenance action near RM 16.7. In the mid-term, slope deficiencies will be corrected through capital projects that include: Lower Russell Road levee setback, and partial work on the Tukwila 205 and Horseshoe Bend levee improvements to address slope stability deficiencies.

**Animal Burrow Inspections and Management**

A total of 39 animal burrows were identified in the USACE deficiencies list. Smoke testing in 2015 indicated that one animal burrow at the Briscoe levee penetrated the entire levee. King County on behalf of the District completed the initial phase of an Animal Burrow Response Pilot Project in 2015 and will continue this study into 2016. Pilot project results will inform completion of an Animal Burrow Management Plan in 2016, to guide future levee inspections, site assessments, response action options and levee repair methodologies. To determine the level of on-going effort in support of longer-term animal burrow management, the pilot program includes the following elements:

- Continue the removal of non-native landward slope vegetation to improve the ability of levee inspectors to locate animal burrows and other possible sources of leakage.
- Refine inspection and documentation procedures and secure resources to do these inspections. Inspect the entire levee system during the first quarter of 2015.
- Complete the literature review begun in 2014 and expand it to include review of other animal burrow programs.
- Develop risk assessment and site prioritization procedures, and use these procedures to evaluate data collected.
- Obtain information on additional control methods identified but not yet researched.
- If control is determined to be warranted, implement a limited-scope program of up to 10 sites. This will require staff resources to manage contractors and crews doing field work and to determine the success of the program.
- Expand the pilot program if necessary to research the burrowing habits of other species known or suspected to create burrows on the Green River levees. At this time these include rabbits, beavers, muskrats, rats, mice and voles.
- Use the information gathered in the course of the pilot project to inform the development of *Animal Burrow Mitigation Plan* for District levees, with specific emphasis on the Green River levees.
- Identify and quantify the resources needed to implement the *Animal Burrow Mitigation Plan* and use this data to evaluate this need against other levee safety needs.

# Chapter 3 Capital Plan

## 3.1 Introduction

The Interim SWIF capital plan is being pursued to ensure that the PL 84-99 levees along the Lower Green River remain eligible for PL 84-99 federal assistance. Pursuing an Interim SWIF is a short-term solution to retain eligibility and does not meet all of the goals and objectives identified by SWIF advisors for the Lower Green River. The District is seeking to achieve, where feasible, these additional goals through individual project opportunities as well as a multi-objective, long term plan that works in concert with implementation of the Interim SWIF.

The capital projects summarized within this chapter are intended to address slope stability deficiencies identified by the USACE that cannot be corrected through routine maintenance activities. These capital investments will also achieve level of protection from flooding goals provisionally approved by the District as well as achieve factors of safety to support future certification and FEMA accreditation. The USACE rates slope stability deficiencies, or over-steepened slopes (typically 1H:1V up to 1.7H: 1V), as "unacceptable" or "minimally acceptable" and these PL 84-99 deficiencies for the Lower Green River levee system are summarized in Table 3.1. Many of these slope stability deficiency locations also have factors of safety values for rapid drawdown that are at or significantly below the minimum acceptable value of 1.0. The intent of the Interim SWIF capital plan is to correct both the slope stability deficiencies and construct a levee or floodwall facility that results in an acceptable factor of safety and is therefore able to be certified. With the exception of the Desimone-Briscoe levee, most of the slope deficiencies summarized in Table 3.1 will be resolved through a capital project. The Desimone-Briscoe slope deficiency (RM 16.7-16.9) will be corrected through a 2016 repair project.

**Table 3.1** PL 84-99 Levees with slope stability deficiencies rated by USACE as "unacceptable" or "minimally acceptable"

| PL 84-99 levee | "Unacceptable" USACE Rated Slope Deficiencies | "Minimally Acceptable" Rated Slope Deficiencies | Total Slope Deficiencies, by Levee | PL 84-99 Corrective Action Type (proposed) |
|---|---|---|---|---|
| **Desimone-Briscoe** | 0 | 1 | 1 | 2016 repair; no SWIF capital project proposed |
| **Horseshoe Bend** | 0 | 4 | 4 | Three SWIF capital projects |
| **Tukwila 205** | 0 | 5 | 5 | Three SWIF capital projects |
| **Lower Russell** | 1 | 0 | 1 | One SWIF capital project (2017) |
| **Totals** | **1** | **10** | **11** | |

## 3.2 Capital Projects

The King County Flood Control District provisionally approved a 500 year (18,800 cfs – measured at Auburn) plus three feet of freeboard flood protection goal for the seven capital project areas included within the Interim SWIF Capital Plan. A second project goal associated with the Interim SWIF capital projects is to achieve site conditions that enable future certification. These capital projects are necessary to resolve nine of the eleven USACE defined PL 84-99 slope deficiencies summarized in Table

3.1. One capital project is located in the vicinity of Lower Russell Road, three capital projects are located along the Tukwila 205 levee, and three capital projects are located along the Horseshoe Bend levee. The remaining two slope stability deficiencies (one each on Tukwila 205 at RM 15.1 and Horseshoe Bend at RM 26.1) will be monitored over time to determine if maintenance or capital actions are needed. Short project summaries and a location map are provided for each proposed capital project.

### 3.2.1 Lower Russell Road (RM 17.85 – 19.25)

**Project Location**

The Lower Russell Road capital project area is located on the right bank of the Lower Green River, between river mile 17.85 and river mile 19.25. The project area is located within the City of Kent and contains a levee that is enrolled in the PL 84-99 system.

**Problem Identification**

This PL 84-99 levee contains an 'Unacceptable' rating by the U.S. Army Corps of Engineer due to a slope deficiency at river mile 18.6. USACE PL 84-99 eligibility inspections identified additional types of PL 84-99 deficiencies: encroachments, animal burrows, erosion, debris, and settling. A portion of the Lower Russell levee was damaged in 1995/96 and repaired in 1997-98 in the vicinity of RMs 17.9, 18.7, 18.9 and 19.2. In addition, there has been significant scour and damage to the levee toe and embankment at RM 18.6 between 2012 and 2015. Levee overtopping in this project area is expected to occur when flows at the Auburn gage are between 15,100 and 18,800 cubic feet per second (cfs), which is an approximately 350- to 500-year flood event.

**Site Context**

The existing PL84-99 levee is located close to the river's edge and protects commercial, industrial and residential land uses in Kent, Renton and Tukwila. Van Dorens Park, the Green River Natural Resources Area and the Green River Regional Trail are located in this project area. Aquatic habitat in this project area is degraded. Riparian habitat is marginal and consists predominantly of grasses, shrubs, and narrow rows of trees. Approximately 82% of the project area's shoreline is considered high priority for increasing shade, per the Muckleshoot Tribe's Solar Radiation Priorities Mapping Study (2013).

**Project Overview**

Design elements include: a stable slope design that meets or exceeds factors of safety; vegetation and trees in accordance with the Draft SWIF Vegetation Plan; and protection to limit the likelihood of potential scour and erosion of the levee. Based on hydraulic modeling, the proposed levee and floodwall are approximately 4 to 6 feet higher than the height of the existing levee. A floodwall is proposed to extend from Veteran's Drive to the PSE corridor at RM 18.8 and then transition to a setback levee from RM 18.8 to S. 212$^{th}$ St (RM 17.85) (see Figure 3.1).

Acquisition of three properties is required to achieve construction of the proposed setback levee, habitat restoration, and relocation of Van Doren's Park.

Additional project components include the following:

- Aquatic and riparian habitat will be enhanced to provide rearing habitat for juvenile salmonids and to cool river temperatures in the Green River.
- Van Doren's Park will be relocated to the east side of Russell Road. The relocated Van Doren's Park will be approximately 10 acres.
- The length of the Green River regional trail will be increased.

- The riverward slopes of the setback levee will have a grade of 3H:1V for increased slope stability.
- Tree and shrub plantings will be included along most of the project length, with some river overlooks and a view picnic area. Aquatic and riparian habitat and reconnected floodplain habitat will total approximately 35 acres.
- Riparian shoreline area available to plant large trees may range from 80-120 feet in width along the floodwall segment, depending on the location of Russell Road and Green River trail. Riparian planting areas north of the PSE corridor will be 100-150 feet wide or more depending on the specific habitat design or constraints such as the KOA campground; the exception to the wider planting zone is the overlook areas.

## Cost Estimate Range

The total estimated project cost range for the Lower Russell project is $41 to 43 million with construction, design and permitting estimated to cost $34-36 million and real estate costs estimated to be $7,000,000.

## Implementation Timing

The Lower Russell Road levee setback project is currently at the 30% design phase, with final design expected to begin in February 2016. The project is scheduled to go to construction in 2018.

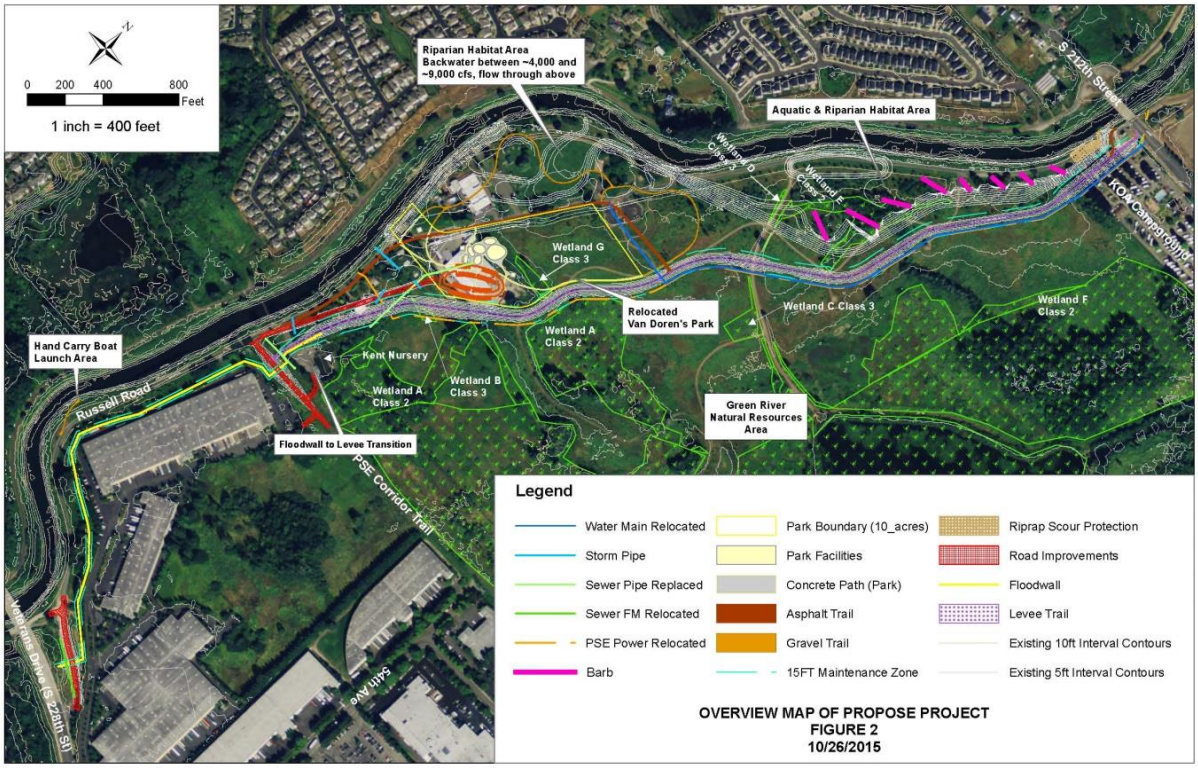



Figure 3.1 Lower Russell Road Levee Setback and Floodwall Project

### 3.2.2 Tukwila 205 Levee (three capital projects)

The Tukwila 205 levee is located on the left bank of the Lower Green River between RM 12.45 and RM 16.72 within the City of Tukwila. The existing PL 84-99 levee is in close proximity to privately owned buildings, parking lots and other land uses, including: commercial/industrial, public facilities, religious facilities, and utilities. Recreational resources in the vicinity of the levee include the Green River Regional Trail. The Tukwila 205 levee was damaged and repaired in 1990, 1992, 1995, 1996, 1997, 2003, 2005, 2008, and 2009 at various locations. The city of Tukwila is currently completing certification studies in advance of pursuing FEMA accreditation for the entire Tukwila 205 levee.

Three capital projects are proposed along the Tukwila 205 levee to correct four PL 84-99 slope stability deficiencies, identified as 'minimally acceptable' by the USACE (**Figure 3.2**). Proposed capital projects along Tukwila 205 will also achieve factors of safety necessary to enable future certification and accreditation. One remaining slope stability deficiency at RM 15.1 will be monitored over time to determine if a maintenance or capital action is needed.

**Figure 3.2. Tukwila 205. Three capital projects address four USACE defined slope deficiencies.**

## Tukwila 205 River Mile (RM) 15.55-15.88: Segale-Green and Gaco-Western

### Project Location

The Tukwila 205 Segale-Green and Gaco-Western capital project area is located on the left bank, between RM 15.55 and 15.88 within the city of Tukwila (**Figure 3.3**).

Figure 3.3 Tukwila 205 Capital Project: RM 15.55 - 15.88 Segale-Green and Gaco-Western Segment

### Problem Identification

This PL 84-99 levee segment is rated as 'Minimally Acceptable' by the USACE due to slope deficiencies: River mile 15.7 (over-steepened slopes range from 1.25H to 1.33H:1V) ; RM 15.4 to 15.7 (over-steepened slopes that are approximately 1.4:1). The Tukwila certification study that is currently underway measured 1.33:1 slopes at RM 15.86 (X-section 10). This study also calculated a Factor of Safety value for rapid drawdown of 0.74 and steady state seepage of 0.88 at RM 15.86. These are below the minimum Factor of Safety of 1.0 from the USACE manual. Additionally, river bed scour in this reach between 1986 and 2011 showed erosion of 7 feet at RM 15.85 and 4.1 feet at RM 15.59 over 25 years. This indicates that the river is actively down cutting in the vicinity of the levee, leading to further over-steepening of the slopes.

### Site Context

The existing PL 84-99 levee is located close to the river's edge and protects commercial/industrial land uses in Tukwila. Aquatic habitat in this project area is degraded. Riparian habitat is degraded and consists predominantly of grasses, and a narrow row of trees near RM 15.8. Approximately 30% of the project area's shoreline is considered high priority for increasing shade, per the Muckleshoot Tribe's Solar Radiation Priorities Mapping Study (2013).

### Project Overview

A 0.33 mile floodwall is the basis for this project proposal and is intended to minimize impacts to adjacent businesses while achieving an embankment design with acceptable factors of safety and necessary toe/scour protection. The constructed embankment slope is proposed to be a minimum 2:1 (and preferably 2.5:1) as measured from the levee crest to the estimated scour depth. The floodwall alignment (including embankment slope, factors of safety, and necessary real estate) would be established during the capital project design phase, after the District initiates the project. Riparian revegetation will be included as part of the capital project design, although site constraints such as the proximity of the proposed floodwall to parking lots and buildings may affect levee slopes and will likely require planting of shrubs and smaller tree species. Based on hydraulic modeling, the proposed floodwall will be approximately 3 to 4 feet higher than the height of the existing levee. Because the

Project involves major modifications to the federal levee here, this will require USACE approval prior to construction.

### Cost Estimate Range

The estimated total project cost for the Segale-Green and Gaco Project is $13,800,000 - $16,600,000 with construction, design and permitting estimated to cost $13,300,000, and $500,000 - $3,300,000 in real estate costs. The low end of the total project cost estimate assumes acquisition of an easement for inspection and achieving minimum factors of safety while the high end includes acquisition of additional space to achieve more stable embankments and higher factors of safety.

### Implementation Timing

The Segale-Green and Gaco-Western (RM 15.55-15.88) project is scheduled to be initiated in 2020 with preliminary design and acquisition; construction is planned for 2022-23.

## Tukwila 205 River Mile RM 14.6-14.75: Ratolo levee segment

### Project Location

The Tukwila 205 - Ratolo capital project area is located on the left bank, between RM 14.6 and 14.75 (**Figure 3.4**). The project area is located within the City of Tukwila.

### Problem Identification

This PL 84-99 levee segment contains a 'Minimally acceptable' rating by the USACE due to a slope deficiency at RM 14.6 (oversteepened slopes from 1.25H:1V for 200-300 feet). The Tukwila certification study measured 1.64:1 slopes at RM 14.72 (X-section 7). This study also calculated a Factor of Safety (FOS) value for rapid drawdown of 0.69 at RM 14.72. This is below the minimum FOS of 1.0 from the USACE manual. River bed scour in this reach between 1986 and 2011 is modest (approximately 1 foot), but there is one known deep scour hole downstream of RM 14.5.

Figure 3.4 Tukwila 205 RM 14.6 - 14.75: Ratolo

### Site Context

The existing PL 84-99 levee is located close to the river's edge and protects commercial/industrial land uses in Tukwila. Aquatic habitat in this project area is degraded. Riparian habitat is compromised and consists predominantly of grasses, shrubs, and a narrow row of trees near RM 14.7. Most

of the project area's shoreline is considered a moderate priority for establishing increased shade, per the Muckleshoot Tribe's Solar Radiation Priorities Mapping Study (2013).

### Project Overview

A 0.15 mile floodwall is proposed to minimize impacts to adjacent businesses while achieving an embankment design with acceptable factors of safety and necessary toe/scour protection. The embankment slope is proposed to achieve a minimum 2:1 (and preferably 2.5:1), as measured from the levee crest to the estimated scour depth. The floodwall alignment (including embankment slope, factors of safety, and necessary real estate) will be finalized during capital project design after the District initiates the project. Riparian revegetation will be included as part of the capital project design, although site constraints such as the proximity of the proposed floodwall to parking lots and buildings may affect levee slopes and will likely require planting of shrubs and smaller tree species. Based on hydraulic modeling, the proposed floodwall is approximately 3 to 4 feet higher than the height of the existing levee. Because the Project involves major modifications to the federal levee here, this will require USACE approval prior to construction.

### Cost Estimate Range

The total estimated cost for the Ratolo Project is $6,300,000 - $7,500,000 with construction, design and permitting estimated to cost $6,000,000 and $300,000 - $1,500,000 estimated for real estate costs. The low end of the estimated project cost range assumes securing easements for inspection and minimum factors of safety while the high end results in additional space to achieve more stable embankments and higher factors of safety.

### Implementation Timing

The Tukwila 205 - Ratolo (RM 14.6-14.75) project is scheduled to be initiated in 2022, with construction in 2024.

## Tukwila 205 River Mile (RM) 13.40-13.58: Christensen Road

### Project Location

The Tukwila 205-Christensen Road capital project area is located on the left bank, between RM 13.40 and 13.58 (Figure 3.5). The project area is located within the City of Tukwila.

### Problem Identification

This PL 84-99 levee segment contains a 'Minimally acceptable' rating by the USACE due to a slope deficiency at RM 13.4 to 13.5 (over steepened slopes from 1.33 to 1.25H:1V for 1000 feet). The preliminary Tukwila certification study measured 1.4:1 slopes at RM 13.53 (X-section 5). This study also calculated a Factor of Safety (FOS) value for rapid drawdown of 0.7 at RM 13.53. This is below the minimum FOS of 1.0 from the USACE manual. River bed scour in this reach between 1986 and 2011 is modest (approximately 1.2 feet).

Figure 3.5 Tukwila 205 RM 13.4-13.58: Christensen Rd.

**Site Context**

The existing PL 84-99 levee is located close to the river's edge and protects commercial and industrial land uses that are immediately adjacent to the levee. Aquatic habitat in this project area is degraded. Riparian habitat is compromised and consists predominantly of grasses. The entire project area shoreline is considered a moderate or high priority for increased shade, per the Muckleshoot Tribe's Solar Radiation Priorities Mapping Study (2013).

**Project Overview**

A 0.18 mile long floodwall is proposed to minimize impacts to adjacent businesses while achieving an embankment design with acceptable factors of safety and necessary toe/scour protection. A minimum 2:1 (and preferably 2.5:1) embankment slope is proposed, as measured from the levee crest to the estimated scour depth. Details on the floodwall alignment (including embankment slope, factors of safety, and necessary real estate) will be worked out during the capital design phase after the District initiates the project. Riparian revegetation will be included as part of the capital project design, although site constraints such as the proximity of the proposed floodwall to parking lots and buildings may affect levee slopes and will likely require planting of shrubs and smaller tree species. Based on hydraulic modeling, the proposed floodwall is approximately three to four feet higher than the height of the existing levee. Because the Project involves major modifications to the federal levee here, this will require USACE approval prior to construction.

**Cost Estimate Range**

The estimated total cost for the Christensen Road project is $7,500,000 - $9,000,000 with construction, design and permitting estimated to cost $7,200,000 and $300,000 to $1,800,000 in real estate costs.

**Implementation Timing**

The Tukwila 205 – Christensen Rd. (RM 13.4-13.58) project is scheduled to be initiated in 2025, with construction in 2027.

### 3.2.3 Horseshoe Bend Levee

The Horseshoe Bend levee is located on the right bank of the Lower Green River between RM 24.25 and RM 26.1 within the City of Kent. This PL 84-99 levee protects commercial, industrial, residential and recreational land uses, with the Green River Trail traveling along the top of the levee for most of its length. This federal levee was raised and improved by the USACE in 1996. In 2012-13, the City of Kent constructed secondary containment structures (flood walls and berms) along portions of the levee, designed to contain 12,000 cfs plus 3 feet of freeboard, to advance the city's certification and accreditation goals. Levee overtopping is expected to occur at flows exceeding 15,100 cubic feet per second (cfs). Portions of the existing Horseshoe Bend levee were damaged/repaired during the following years: 1991, 1994, 1996, 2003, 2006, and 2009.

Three levee segments along the Horseshoe Bend levee contain three slope stability deficiencies, identified as 'minimally acceptable' by the USACE (Figure 3.6). The Breda reach has the lowest Factor of Safety rating (1.005) of the Horseshoe Bend levee, considered a "just-stable" condition in comparison to the minimum factor of safety of 1.0 from the USACE manual.

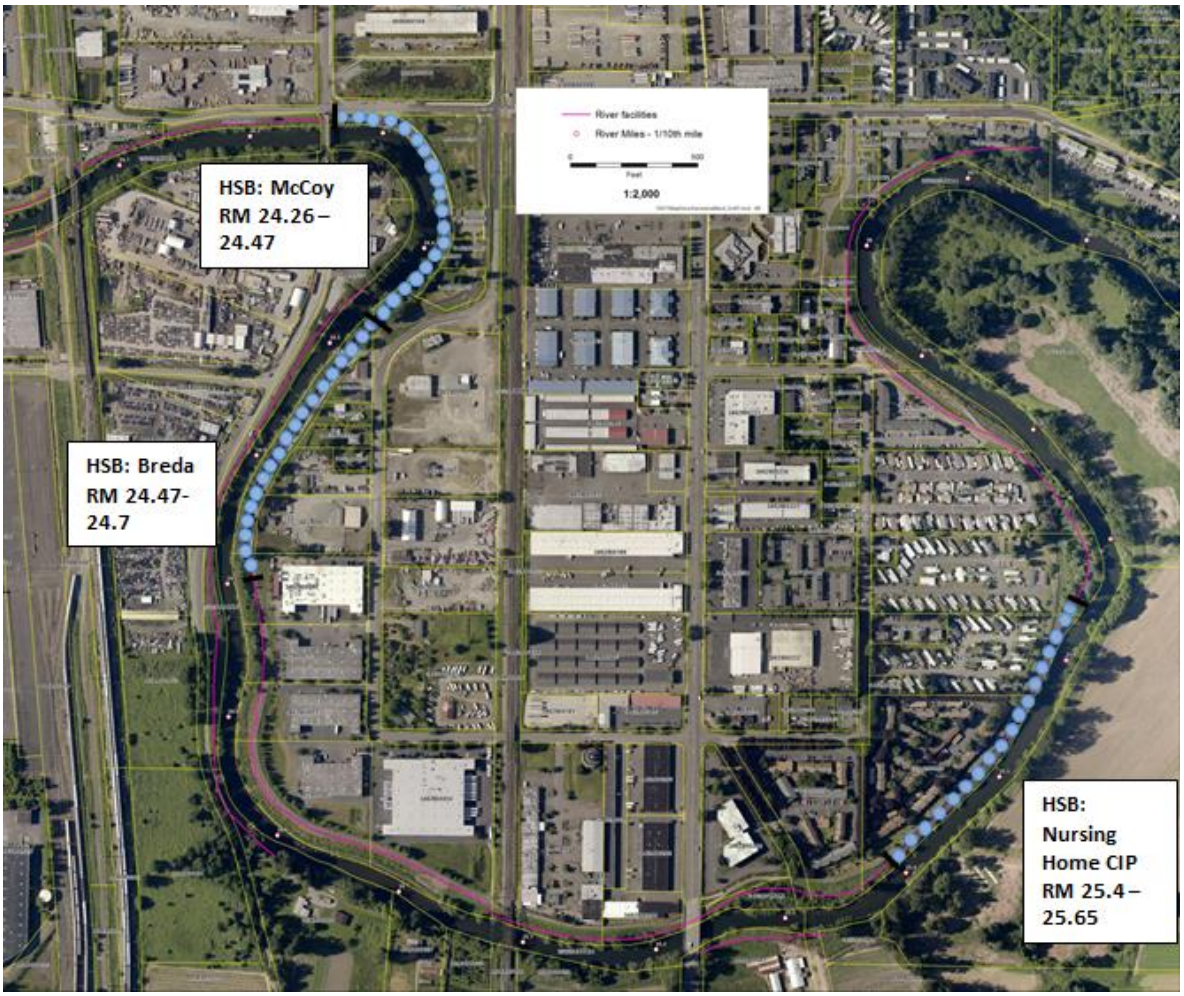



Figure 3.6 Horseshoe Bend Levee: three PL 84-99 slope deficiency locations

## Horseshoe Bend River Mile (RM) 24.26-24.47: McCoy

### Project location

The Horseshoe Bend McCoy capital project area is located on the right bank, between RM 24.26 and 24.47 within the City of Kent (Figure 3.7).

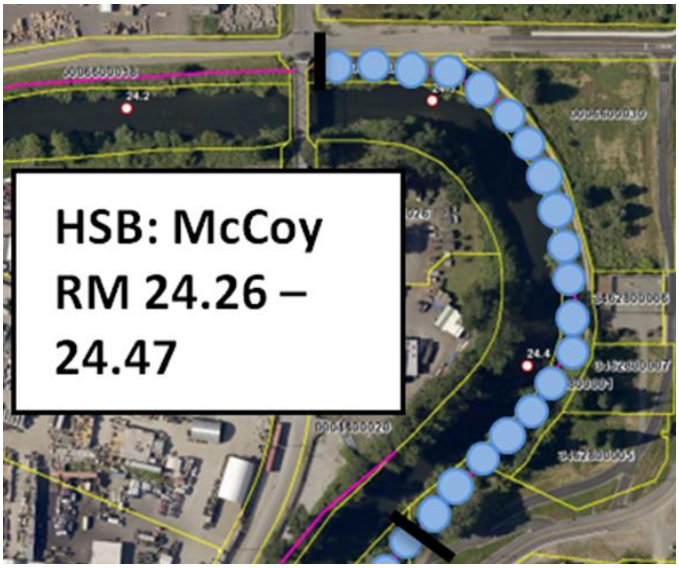



Figure 3.7 Horseshoe Bend RM 24.26-24.47: McCoy

### Problem identification

This PL 84-99 levee segment contains a 'Minimally acceptable' rating by the USACE due to a slope deficiency at RM 24.3 (oversteepened slopes from 1.3 to 1.7H:1V for 500 feet). The City of Kent constructed a secondary containment levee in this reach, set back from the river's edge, which is currently not part of the federal levee. The only remaining structure between the two levees is a Puget Sound Energy facility. The Horseshoe Bend Levee Certification Report calculated Factor of Safety (FOS) values for rapid drawdown of 1.08 and 1.55 at about RM 24.3 and RM 24.4, respectively. River bed scour in this reach between 1986 and 2011 is 2.7 feet at RM 24.24.

### Site Context

The existing PL 84-99 levee is located close to the river's edge and protects commercial and industrial land uses that are landward of the levee. Aquatic habitat in this project area is degraded. Riparian habitat is degraded and consists predominantly of grasses, shrubs, and trees. The entire project area shoreline is considered a high priority for achieving increased shade, per the Muckleshoot Tribe's Solar Radiation Priorities Mapping Study (2013).

### Alternatives

Two capital project alternatives are proposed for future evaluation:

- Alternative One – Submit a request to the USACE for a major modification to the Horseshoe Bend facility, from RM 24.26-24.47. The proposed project would result in a levee alignment that follows the City of Kent's recently constructed secondary levee, that is currently set back from the Green River.
- Alternative Two – If a major modification is not approved by the federal government, or proves to be infeasible, an in-place replacement of the existing riverward levee or a modestly setback levee should be constructed to achieve a 500-year level of protection, stable embankment and adequate toe/scour protection.

### Project Overview

The major modification process for a federal levee involves the following steps: pre-coordination, a written request, required documentation (e.g., technical analysis and design, hydrologic and hydraulic analysis, environmental compliance, real estate requirements, operations and maintenance, etc.),

USACE-led technical review, summary of findings, decision and notification. Much of the existing technical material and information on the design and construction of the secondary levee is available from the City of Kent. Also, the real estate in this project area is owned by the City of Kent and King County Parks.

### Cost Estimates for Two Project Alternatives

Alternative One – The cost associated with completing a modification to the existing federal levee is estimated to be up to $400,000. A major modification to a federal levee requires the local sponsor (King County Flood Control District) to fund the USACE to carry out this modification process. The estimated USACE cost is $100,000 and the duration is 12-18 months. Additional costs to compile material, technical analysis, and support USACE review is expected to be $100,000 – $250,000. This project alternative would not require a capital design or construction phase to be funded. However, the recently completed secondary containment levee is designed only to the 100-year level of protection.

Alternative Two – The cost of an in-place replacement is roughly estimated to be $4.7 million.

### Implementation Timing

Implementation timing for a major modification to the existing levee (project team recommended project alternative) is 2017-18. The second alternative, if necessary, is scheduled for project initiation in 2025, with construction in 2027.

## Horseshoe Bend River Mile (RM) 24.47-24.7: Breda

### Project Location

The Horseshoe Bend Breda capital project area is located on the right bank, between RM 24.47 and 24.7 within the City of Kent (Figure 3.8).

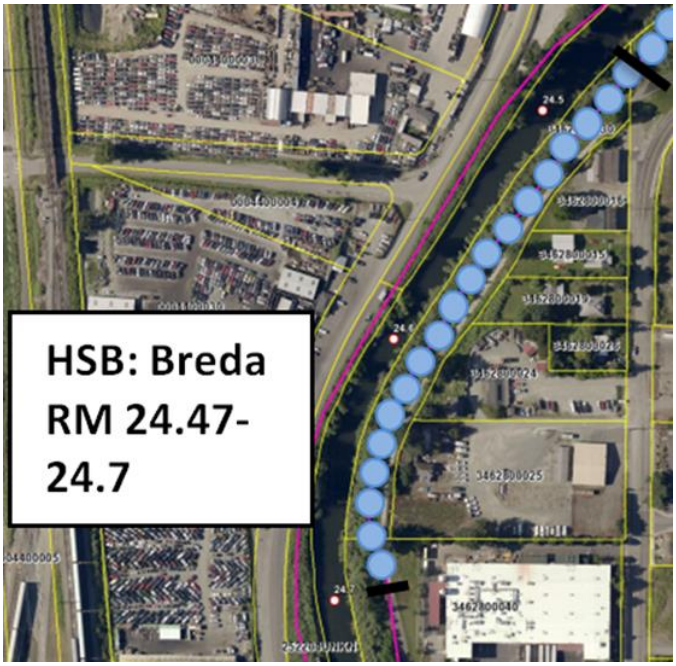



Figure 3.8 Horseshoe Bend RM 24.47-24.7 Breda

### Problem Identification

The Breda portion of the Horseshoe Bend levee does not meet recommended structural engineering design standards. The existing levee system is vulnerable to undercutting scour due to narrow channel confinement, together with marginal stability resulting from over-steepened levee slopes and recent fill placement to achieve freeboard along the levee crest. Recent improvements were made to the downstream levee by City of Kent (secondary containment levee from RM 24.3 to 24.47) and upstream by the USACE (2009 repair of launchable toe rock and embankment from RM 24.79-25.01). The Horseshoe Bend Levee Certification Report calculated a Factor of Safety (FOS) value for rapid drawdown of 1.005 at RM 24.57 (Section C). This is the lowest along the entire

Horseshoe Bend levee and barely above the minimum FOS (1.0) from the USACE manual. River bed scour in this reach between 1986 and 2011 was 3.7 feet at RM 24.59.

### Site Context

The existing PL 84-99 levee is located close to the river's edge and protects commercial and industrial land uses in Kent that are landward of the levee. Aquatic habitat in this project area is degraded. Riparian habitat is compromised and consists predominantly of grasses, shrubs, and trees. The entire project area shoreline is considered a high priority for achieving increased shade, per the Muckleshoot Tribe's Solar Radiation Priorities Mapping Study (2013).

### Project Overview

A 0.23 mile long levee setback is proposed that would tie into two levee segments, upstream and downstream of the project area, that were recently completed by the USACE and City of Kent, respectively. The intent of the project is to construct a levee setback to achieve an embankment design with acceptable factors of safety and necessary toe/scour protection, while reducing erosive velocities and enabling enhanced riparian vegetation. A minimum embankment slope of 2.5:1 (and preferably 3:1) is proposed, from the levee crest to the estimated scour depth. Details on the setback levee alignment are proposed to be worked out during the capital project design process, after the District initiates the project. With a setback of the levee in this capital project location, it may be possible to construct a wider levee bench as illustrated in Chapter 5 (vegetation plan), to maximize riparian revegetation and achieve increased number of shade trees proximate to the river. Based on hydraulic modeling, the proposed levee is approximately 4 to 5 feet higher than the height of the existing levee. Because the levee is set back from the river, the facility will require lower long-term maintenance costs.

The proposed capital project will require additional easements or fee-simple land rights to provide for the raised and relocated levee structure. Because the Project involves major modifications to the federal levee here, this will require USACE approval prior to construction.

### Cost Estimate Range

A cost estimate for this project is $6,900,000 to $8,600,000. A breakdown of this estimate includes: $5,100,000 for construction, design and permitting and between 1,800,000 - $3,500,000 for real estate acquisition.

### Implementation Timing

There is currently placeholder funding in the Flood Control District budget for the Horseshoe Bend Acquisition and Reconstruction project. The Breda reach is one of the most at risk segments of the levee needing improvement. Available funding in the 2015 budget for this project is approximately $2.5 million. This would allow acquisition of some of the initial key parcels necessary to enable construction and the initiation of preliminary design work. Project design is proposed to start in 2018 with construction to be initiated in 2020.

## Horseshoe Bend River Mile (RM) 25.4-25.65: Nursing Home

### Project Location

The Horseshoe Bend Nursing Home capital project area is located on the right bank, between RM 25.4 and 25.65 within the City of Kent (Figure 3.9).

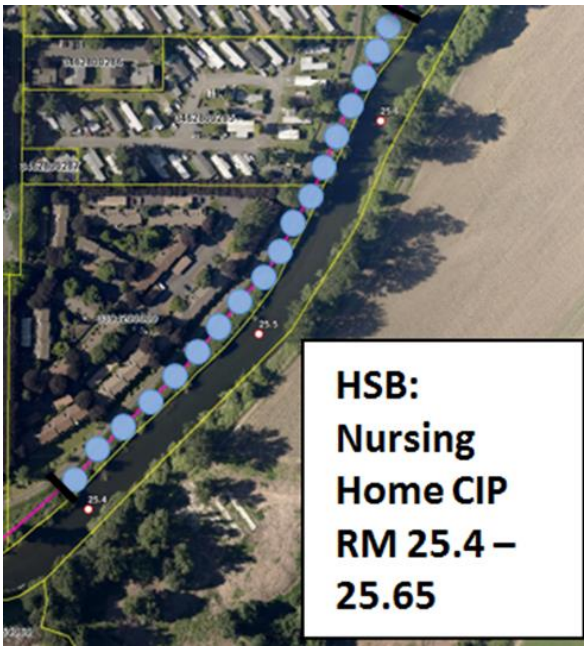


Figure 3.9 Horseshoe Bend RM 25.4-25.65 Nursing Home

### Problem Identification

This capital project area contains a 'Minimally Acceptable' deficiency by the USACE at RM 25.5 (over steepened slopes from 1.25 to 1.7H:1V for 225 feet). The Horseshoe Bend Levee Certification Report calculated a Factor of Safety (FOS) value for rapid drawdown of 1.01 at RM 25.57 (Section F). This is barely above the minimum FOS (1.0) from the USACE manual. River bed scour just upstream of this reach between 1986 and 2011 is 1.3 feet at RM 25.85.

### Site Context

The existing PL 84-99 levee is located close to the river's edge and protects residential, commercial and industrial land uses located landward of the levee. Aquatic habitat in this project area is degraded. Riparian habitat is compromised and consists predominantly of grasses and shrubs, with some trees at the upstream end. The project area shoreline is considered a moderate to low priority for achieving increased shade, per the Muckleshoot Tribes Solar Radiation Priorities Mapping Study (2013).

### Project Overview and Alternatives

Two possible alternatives for this 0.25 mile long project include: a floodwall or an in-place replacement. In 2009, USACE completed a 160 foot repair near RM 25.6 and an 1140 foot repair between RM 25.79-26.0. The proposed project (either a floodwall or an in-place levee replacement, pending future decisions by the District) would achieve an embankment design with acceptable factors of safety and necessary toe/scour protection. The embankment slope is proposed to be a minimum 2:1 (and preferably 2.5:1) as measured from the levee crest or floodwall to the estimated scour depth. The alignment of the floodwall or levee (including embankment slope, factors of safety, and necessary real estate) would be established as part of the capital project design phase, once the District initiates the project. Based on hydraulic modeling, a floodwall would need to be approximately 4 to 5 feet higher than the height of the existing levee. Riparian revegetation will be included in the design, as feasible, although site constraints at this site may affect levee slopes and will likely require planting of shrubs and smaller tree species. Because the Project involves major modifications to the federal levee here, this will require USACE approval prior to construction.

### Cost Estimate Range

Alternative 1 (in-place levee replacement): The total cost estimate for an in-place replacement levee is $8,700,000, with construction, design and permitting estimated to cost $4,900,000 and $3,800,000 for real estate acquisition.

Alternative 2 (floodwall): The total cost for a floodwall is $10,700,000 to $11,700,000 with construction, design and permitting estimated to cost $10,200,000, and $500,000 to 1,500,000 for real estate acquisition.

**Implementation Timing**

The Horseshoe Bend – Nursing Home (RM 25.4-25.65) project is scheduled to be initiated in 2022, with construction in 2024.

## 3.3 SWIF Capital Project Cost Summary

Table 3.2 summarizes estimated costs for all proposed SWIF capital projects needed to resolve USACE defined PL 84-99 slope deficiencies.

| INTERIM SWIF Capital Projects | Construction, Design, Permitting and Administration Estimates | Real Estate Acquisition Estimates | Total Cost Estimate* |
|---|---|---|---|
| **Lower Russell Rd.** | $34,000,000 – $36,000,000 | $7,000,000 | $41,000,000 - $43,000,000 |
| **Tukwila 205** | | | |
| **Segale-Green Gaco-Western** | $13,300,000 | $500,000 - $3,300,000 | $13,800,000 - $16,600,000 |
| **Ratolo** | $6,000,000 | $300,000 - $1,500,000 | $6,300,000 - $7,500,000 |
| **Christensen Rd.** | $7,200,000 | $300,000 - $1,800,000 | $7,500,000 - $9,000,000 |
| **Horseshoe Bend** | | | |
| **McCoy** | Alt 1: Major Modification<br>Alt 2: $4,700,000 | Alt 1: n/a<br>Alt 2: n/a | Alt 1: $400,000<br>Alt 2: $4,700,000 |
| **Breda** | $5,100,000 | $1,800,000 - $3,500,000 | $6,900,000 - $8,600,000 |
| **Nursing Home** | Alt 1: $4,900,000<br>Alt 2: $10,200,000 | Alt 1: $3,800,000<br>Alt 2: $500,000 - $1,500,000 | Alt 1: $8,700,000<br>Alt 2: $10,700,000 - $11,700,000 |

* Note: Lower Russell costs based on 30% design; all other costs based on planning level cost estimates for design, construction, and acquisition, including contingency.

# Chapter 4 Vegetation Plan

## 4.1 Introduction

A Vegetation Plan for the PL 84-99 shoreline portions of the Lower Green River was prepared as part of the Green River System Wide Improvement Framework Interim Report, to provide recommendations to guide the design, maintenance and long-term stewardship of shoreline vegetation in the vicinity of levees and floodwalls enrolled within the federal PL 84-99 program.

For purposes of the Interim SWIF, this chapter provides guidelines to inform maintenance, repairs and capital projects associated with Lower Green River shorelines that contain PL 84-99 enrolled levees and floodwalls. Though vegetation is no longer one of the deficiency categories by which the USACE determines levee or floodwall eligibility for the PL 84-99 Program (*Interim Policy for Determining Eligibility Status of Flood Risk Management Projects to Rehabilitation Program, Pursuant to PL 84-99,* March 2014), ensuring inspection viability is still a consideration. The King County Flood Control District has prepared a Vegetation Plan to ensure that SWIF implementation results in levees and floodwalls that function as designed, can be inspected, are complementary to local land uses, while also in compliance with the Clean Water Act and Federal Endangered Species Act.

With completion of the Green River SWIF Interim Report and associated acceptance of this Vegetation Plan by the USACE, King County does not anticipate future tree removals along PL 84-99 shorelines unless an individual tree is determined to be a hazard tree for public safety or levee integrity purposes.

Current shoreline vegetation conditions of the Lower Green River are variable. Depending upon location, the vegetation ranges from sparsely vegetated and physically constrained, over-steepened slopes to shorelines that have enough space to support ample, diverse assemblages of trees, shrubs and plants. Much of the Lower Green River shoreline is constrained by impervious surfaces associated with commercial, industrial, and residential land uses (Figure 4.1). Typically, the closer the buildings, roads and parking lots are to the top of a levee, the more likely the shoreline vegetation is dominated by blackberry, ivy and other invasive shrub species. In these locations, which include much of the 16 miles of currently enrolled, PL 84-99 leveed shorelines, there is not enough space available to support mature, tall canopied trees or a diversity of native plant, shrub and tree species.

**Figure 4.1. Typical Lower Green River PL 84-99 shoreline with little vegetation and river channel that is constrained by land uses**

With sufficient space and gentler riverbank slopes, shoreline conditions along the Lower Green River could support additional vegetation, including tall shoreline trees (Figure 4.2). The Department of Ecology published the Green River Temperature Total Maximum Daily Load: Water Quality Improvement Report (June 2011). One recommendation from this report included planting additional shoreline shade trees for the purposes of reducing elevated water temperatures in the Green River. Benefits associated with carefully planted and stewarded shoreline vegetation include: increased shade to the main channel; native shrubs that provide micro habitat and climatic benefits; improved shoreline stability in areas prone to erosion and slope failure; and overall, an improved condition for people, fish, farmers and the community at large.

**Figure 4.2. Vegetated shoreline on the Lower Green River**

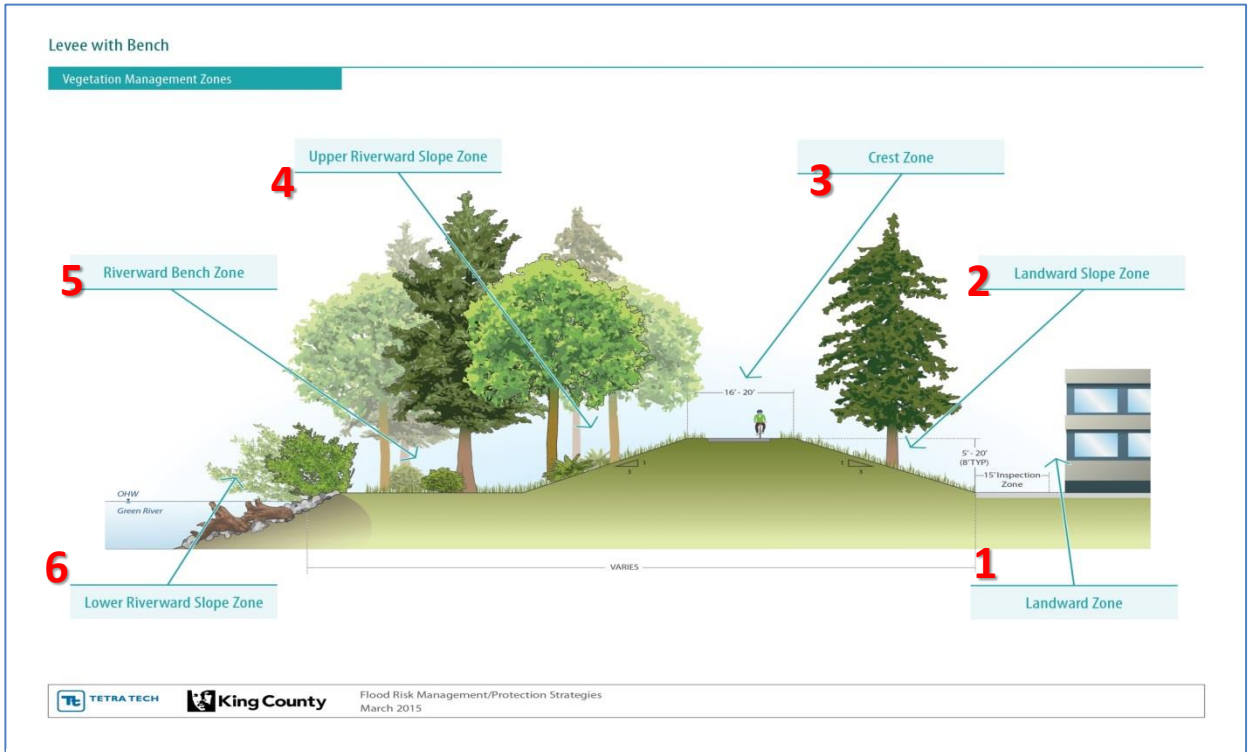



**Figure 4.3. Target shoreline vegetation structure for the Lower Green River. Six management zones are proposed for PL 84-99 shorelines to guide future capital project design, repairs, and maintenance activities.**

Figure 4.3 illustrates a possible future condition for Lower Green River shorelines, one with sufficient space to support well-functioning, PL 84-99 eligible levees and accompanying vegetation, tall trees, and recreational trail features. The SWIF Vegetation Plan recommendations reflect a careful evaluation of levee integrity, water temperature, habitat and public use considerations.

The Green River SWIF Vegetation Plan is structured to achieve the following outcomes, as part of Interim SWIF implementation:

- More predictable and consistent levee operations and reliability, as well as vegetation management and maintenance practices to support the annual inspections of PL 84-99 levees by King County and the USACE;
- Improved riparian habitat and shade conditions along the main channel of the Lower Green River, along PL 84-99 shorelines;
- Better alignment of flood risk management activities with requirements to protect and restore natural resources of the Green River, and to address environmental issues associated with the Endangered Species Act and Clean Water Act;
- Riparian vegetation communities on PL 84-99 shorelines that complement adjacent land uses, including parks, recreational trails, farms, commercial/residential development and other land uses.

These shoreline vegetation outcomes will be achieved primarily through implementation of a prioritized SWIF Capital Plan and accompanying programs and policies. Together these actions are intended to resolve USACE defined deficiencies along 16+ miles of levees that line the Lower Green River shoreline, while advancing river and floodplain management goals established through the SWIF planning process.

Individual SWIF capital projects will have variable amounts of space that is available for design, construction and long-term stewardship purposes. Accordingly, the Vegetation Plan is not prescriptive but is intended to serve as a starting point for individual capital project design teams of funded capital projects. The Vegetation Plan's proposed approach to designing and managing vegetation according to vegetation management zones will result in more consistent and predictable maintenance, operations and stewardship of vegetation along shorelines. It is beyond the scope of the Vegetation Plan to provide detailed vegetation guidance for shorelines without PL 84-99 levees, of which there are approximately 17 miles along the Lower Green River.

## 4.2 Vegetation Management Zones

Vegetation management zones are linked to specific portions of a Lower Green River PL 84-99 shoreline that contains a levee or floodwall. Each zone shares common structural characteristics for which there are related management considerations associated with PL 84-99 program eligibility; levee integrity; water temperature, vegetation, and habitat; and public use and safety. A target vegetative structure is proposed for each Vegetation Management Zone that reflects a balanced approach to designing and maintaining structurally safe levees and floodwalls.

Six vegetation management zones for PL 84-99 shorelines (**Figure 4.3 and Table 4.1**) are proposed to achieve the following outcomes: plant/tree species selection guidance, location (specifically new trees, with respect to the internal levee core prism); vegetation densities; and long-term vegetation maintenance, operations and stewardship practices in the vicinity of current and potential future PL 84-99 shorelines. This vegetation management zone guidance is not intended to be prescriptive, but is intended to guide design, construction and long-term maintenance and operations, and decision-making. These concepts may be customized to best serve the unique conditions of each individual PL 84-99 shoreline reach.

**Table 4.1. PL 84-99 Vegetation Management Zones (VMZ) definitions**

| # | Name | VMZ physical location, along PL 84-99 shoreline |
|---|---|---|
| **VMZ** 1 | Landward Zone | Area landward of the landward toe of a levee or floodwall, includes a 15' inspection zone. |
| **VMZ** 2 | Landward Slope Zone | Landward slope of the levee or floodwall |
| **VMZ** 3 | Crest Zone | Top of the levee |
| **VMZ** 4 | Upper Riverward Slope | Top portion of the riverward slope, between the bench and top of bank |
| **VMZ** 5 | Riverward Bench Zone | Flat bench that could be located at variable elevations on the riverward slope |
| **VMZ** 6 | Lower Riverward Slope Zone | Edge of water, upslope to the bench, or if no bench, to the lower edge of the upper riverward slope |

In applying these vegetation management zone guidelines, site-specific benefits and risks should be taken into account and vegetation planting and maintenance adjusted accordingly. Understanding the potential effects of trees and other vegetation on levee integrity, channel roughness and other site-scale considerations (see Table 4.2) will be evaluated as part of future designs and planting plans for PL 84-99 levee and floodwall capital projects. For example, in locations in which the establishment of tall trees would substantially increase shade on the river, the risk associated with having trees on the levee prism may be more warranted than in other locations where the potential to create shade is negligible. Similarly, management of the riparian vegetation should be evaluated with respect to public safety, public access and frequency of view opportunities along the river.

## 4.3 PL 84-99 Shoreline Types

All PL 84-99 shorelines along the Lower Green River can be roughly categorized, as a function of their design, age and vegetative structure into one of three types:

**Shoreline Type A. Original levee construction and subsequent repairs.** This shoreline type accounts for the majority of the Lower Green River PL 84-99 shoreline. These leveed shorelines were constructed in the 1960s and are characterized by limited native vegetation, few trees, significant invasive plant species such as Himalayan blackberry (Figure 4.4), significant rock on the riverward slopes, and a lack of contemporary design standards.

**Figure 4.4. PL 84-99 shoreline Type A: original levee construction that in some locations, have received repairs.**

**Shoreline Type B. Bioengineered Levees.** A subset of PL 84-99 levees were repaired using bio-engineered design strategies that incorporated native vegetation and the creation of gentle shoreline benches, whenever possible, for planting purposes (Figure 4.5). Some of these bio-engineered repair projects are over twenty years old and have received varying levels of maintenance and/or stewardship. As feasible, forthcoming Interim SWIF capital project designs will retain existing native vegetation located at the riverward toe of the shoreline slope.

**Figure 4.5. PL 84-99 shoreline Type B: bioengineered repairs**

**Shoreline Type C. Recently Built Capital Projects.**
Recently completed, or soon-to-be completed large capital projects including the Reddington levee setback project in Auburn (Figure 4.6), as well as multiple floodwalls and secondary containment structures on the right bank within the cities of Kent and Tukwila (Figure 4.7). Vegetation in this category is typically young, newly established and is being monitored to ensure permit compliance. Vegetation in some newly constructed and planted PL 84-99 shoreline areas is not consistent with the vegetation management zone guidelines presented in this chapter. For example, in a few locations along the Reddington levee's shoreline, shade trees were not planted riverward of the newly constructed Reddington levee, per the specification outlined for Vegetation Management Zones 4 and 5 (Figure 4.3). Over time, it may be possible to plant additional trees in these locations to enhance shade provided to the main channel of the river.

**Figure 4.6. Shoreline Type C: Reddington levee setback in City of Auburn**

**Figure 4.7. PL 84-99 Shoreline Type C: recently constructed floodwall in City of Kent**

## 4.4 Shoreline Shade Trees: Considerations and Risk Assessment

Current Lower Green River riparian vegetation conditions do not meet the necessary shade conditions, as recommended within the Department of Ecology's Green River Total Maximum Daily Load (TMDL) Report. The report provided a recommendation to establish 150 foot wide buffers comprised of large trees that reach a height of 100+ feet, along the 21 mile long Lower Green River, as a means of achieving Lower Green River water temperature standards. Currently, there is no approved TMDL Implementation Plan for the Lower Green River, so shoreline shade tree strategies serve as a recommendation rather than a legal requirement. The TMDL is important technical guidance for the Green River SWIF and the Interim SWIF Capital Plan will strive to achieve increased numbers and densities of shoreline shade trees through capital project design and construction, and ongoing approaches to vegetation management and maintenance in the vicinity of PL 84-99 shorelines.

The Vegetation Plan provides design guidance for large shade trees. In conjunction with balancing levee integrity, ecological, land use and other considerations, large trees would be planted most densely in vegetation management zones 4, 5 and 6 (riverward slope and riverward bench), and less densely in Vegetation Management Zone 2 (landward slope). Shade tree planting (spacing and location), as part of SWIF Capital Plan implementation, will be informed by the location of the internal levee core prism), location of trail/access road typically located on the top of the levee crest, or location/depth/type of floodwall.

Trees planted and maintained in the vicinity of PL 84-99 shorelines may require site-specific tree risk assessments to determine whether potential hazard trees on the riverward or landward slope of the levee warrant removal to preserve levee integrity. Once a tree on a levee falls, the pit created by the tree's root ball is susceptible to erosion and will likely result in damage to the levee if not stabilized. Removing hazard trees before they fall will reduce the need for future repair projects.

Site-specific tree risk assessments will be completed to help guide maintenance actions for trees when site conditions suggest the tree could pose a hazard to the levee. For example, if a large tree is leaning precariously (or there are other indicators of instability) and is located on the riverward slope, a risk assessment will be completed. Removal of the tree may be necessary, and a site-specific assessment would assist in making this determination.

## 4.5 Vegetation and Capital Project Design

Achieving enhanced vegetation in the vicinity of levees and floodwalls enrolled in the PL 84-99 program, requires sufficient space, between the PL 84-99 facility and the river's edge, to support large trees and other specified vegetation. Vegetation guidance within this Plan is intended to be scaled up or down, as a function of the quantity of space that is available in the vicinity of levees or floodwalls, to support large shade trees and other riparian vegetation, without compromising levee integrity. The amount of space each capital project will have between the river's edge and the levee or floodwall will determine how much and what types of vegetation will be possible to plant and sustain over time.

Achieving sufficient space to support large shade trees and other ecological and social objectives is easier when levees are set back from the river. The recently completed Reddington levee setback illustrates this concept; the existing PL 84-99 levee was rebuilt in a landward location which in turn provided sufficient space between the newly constructed levee and the river to accommodate a multiple use trail on the levee crest, as well as riparian vegetation, trees and other habitat features on

the riverward side of the levee prism. The planned Lower Russell Road Project (Chapter 3) is a similar levee setback project.

Less space is typically available to support vegetation and other outcomes with in-place PL 84-99 levee replacements or floodwalls that are located within 100 feet of the river. Once funded, a capital project design process will ensure that stable slopes, toe scour protection, and other factors of levee safety are met. In addition to the amount of space available to construct a SWIF capital project, other criteria that will be used for design of structurally sound levees and floodwalls as well as healthy vegetation and trees include:

- **Levee slopes**. Ideal levee slopes will be 3:1 riverward and landward. In some cases, a steeper levee slope of 2.5:1 or less may be possible, if acceptable factors of safety can be achieved.
- **As-built levee or floodwall elevations**. Achieving the 500-year provisionally approved flood protection goal (18,800 cfs + 3 feet of freeboard) will determine the height of levees and floodwalls at individual project sites.
- **Inner levee core prism**. USACE design standards support a variable height between elevation of levee crest and elevation of minimum levee core. Internal levee core prism details to consider (Figure 4.**8**):
    - Crest width = 10 feet
    - 2:1 slope
    - 10 – 100 year elevation for urban levees; this equates to a flow of 12,000 cfs at Auburn for both the 10 and 100 year median estimate
- **Tree pull out pits**. Large trees can be planted on the riverward slope (vegetation management zones 2, 4, 5 and 6), so long as the tree pull out pit does not intrude into the internal levee core prism.
- **Riverward toe protection**. In vulnerable riverward toe locations, scour protection with associated native shrubs and trees that can tolerate frequent inundation.

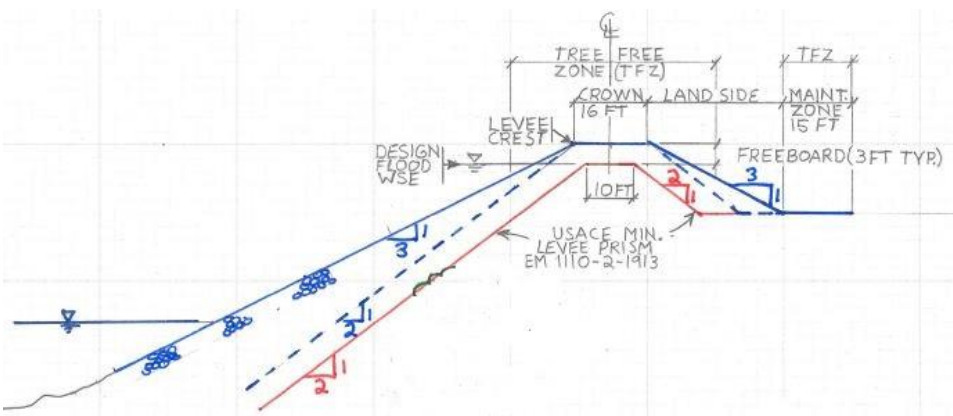



**Figure 4.8. Levee slopes for inner core prism and exterior prism**

## 4.6 Maintenance and Stewardship of Vegetation on PL 84-99 Shorelines

Existing trees and vegetation on PL 84-99 shorelines, as well as newly planted capital project areas, require active maintenance and monitoring to ensure that inspections can occur and that the target vegetative structure associated with each vegetation management zone is achieved. Though shorelines may have the potential to meet the objectives associated with each proposed vegetation management

zone, it may not always be possible to achieve these desired outcomes due to site constraints, such as adjacent land uses that are proximate to landward slopes of the levee or floodwall.

King County will continue to manage and maintain existing vegetation along PL 84-99 enrolled levees. Vegetation management will support inspections by King County and the USACE for levee integrity and functionality. This section of Chapter 4 outlines vegetation maintenance and stewardship recommendations for PL 84-99 shorelines, including existing enrolled levees and floodwalls as well as newly constructed capital projects. For vegetation maintenance and operations purposes, it is important to distinguish that approaches and associated costs vary according to flood protection facility type, and other characteristics such as vegetation types, structural design, and management history.

### 4.6.1 PL 84-99 Shoreline Type A: Original Levee Construction and Repair (pre-bioengineering)

Prior to the advancement of bioengineering and levee setbacks as a means of repairing damaged levee systems, failing bank armor was replaced with little or no attempt to re-establish native vegetation along the shorelines. Over time, the rock armor in these areas has become filled in, and in most cases covered, with sand and silt which supports plant communities dominated by invasive reed canarygrass and Himalayan blackberry. In a few locations robust stands of willow and dogwood have become established and are able to effectively shade out these invasive species.

The primary maintenance activity for these original levees is upper bank slope mowing conducted as part of trail maintenance programs, and annual slope mowing by King County prior to the flood season to aid in levee inspections and meet USACE requirements. Slope mowing targets primarily non-native vegetation, predominantly reed canary grass and Himalayan blackberry, allowing the limited native vegetation to remain.

Removal of nearly 500 trees in 2008 and 2009 to meet PL 84-99 eligibility requirements resulted in the loss of many trees from the landward and riverward slopes, as well as trees planted on bioengineered mid-slope benches. With completion of the Green River SWIF Interim Report and associated acceptance of this Vegetation Plan by the USACE, King County does not anticipate future tree removals along PL 84-99 shorelines unless an individual tree is determined to be a hazard tree. Ongoing control of noxious and invasive weeds throughout the levee system is also a routine part of King County's levee maintenance program.

In summary, vegetation management recommendations for Type A shorelines are:

- Slope mowing, prior to the flood season
- Noxious weed control
- Tree management. Evaluation of trees both with respect to the Vegetation Plan and standard hazard tree assessment protocols. Corrective actions (tree removals or alterations) will be taken when necessary. Any removal of trees that threaten the integrity of the levee or are determined to be unsafe will need to be mitigated to meet local, state and federal regulations.

### 4.6.2 PL 84-99 Shoreline Type B: Early Bioengineering Repairs and Bench Back Projects

Approximately 53 levee or revetment repairs were constructed by King County or the USACE along the Green River between 1990 and 2012; 46 had bioengineered elements. Due to the evolving nature of the design approaches to levee repairs, varying site conditions and construction of projects by King County and the USACE, the vegetation structure in these project areas varies. However, in general, they are characterized by a riverward toe constructed with rock, wood, or a combination, geogrids with willow and dogwood stakes, the construction of a mid-slope riverward bench (if there was sufficient room) to

allow for establishment of tree species, and upper riverward slopes either planted with grass or shrubs. In a few cases native vegetation was planted on the landward side of the levee, but in most cases landward vegetation was determined by the adjacent land-use.

In some cases, earlier bioengineered projects were compromised, over time, by landowner trimming or removal of planted vegetation. In most cases, maintenance of these new project areas focused on the establishment of native plants and the removal of invasive species. In one location, willows have been routinely thinned to encourage the growth of slower growing tree species on the riverward bench. In most locations, the rapid growth of willows, paired with minimal willow thinning, has limited the successful establishment of large trees. Future vegetation maintenance actions will target willow thinning in specific locations where dense shrubs may out-compete newly planted shade trees.

As the bioengineered projects have matured and in some cases grown into dense thickets, vegetation has limited inspection of the levees from the crest as well as impacted recreational trail user views to the river. In two locations revegetation has been so successful that some native plants have had to be cut back to keep them from growing onto the paved trails.

These repaired levees do not meet the provisionally approved 500-year flood protection and improved slope stability goals that will be achieved through SWIF Capital Plan implementation. Interim vegetation management will need to take place for these repaired levee sites, prior to completion of a future Capital Project.

In summary vegetation management recommendations for type B shorelines are:

- Thinning vegetation as needed to allow flood facilities to be inspected, and in some cases, to create intermittent view of the river from the levee crest
- Establishment and maintenance of primitive inspection trails on the constructed benches to allow inspection of the lower part of the upper riverward slope and the lower riverward slope
- Conducting inspections during relatively low flow periods during the early spring when deciduous shrubs do not have leaves
- Minimal thinning of willows growing vertically along the shoreline, but not over the water, to allow more light for slower growing trees planted on the benches
- Protection of existing trees and planting of new trees, in a coordinated manner with SWIF capital plan implementation
- Removing all vegetation except grass from the levee crest, and 8-10 feet down from the levee crest on the riverward slope (VMZ 4)
- Ongoing invasive species and noxious weed management

### 4.6.3 PL 84-99 Shoreline Type C: Recently Planted Levee Setbacks and Floodwall Projects

Four recently completed Lower Green River flood protection projects (Reddington levee setback project and the Briscoe-Desimone Sites 1-3 floodwall projects) contain newly planted vegetation that requires ongoing maintenance and stewardship. These projects occupy a unique niche in the discussion on long term levee vegetation management, as their design was not informed by the vegetation guidelines presented within this Interim SWIF. Some recent projects, such as Briscoe–Desimone Sites 2 and 3 will likely require additional toe protection work, thereby presenting an opportunity to incorporate additional vegetation at that time.

Maintenance and stewardship recommendations for recently completed setback levees and floodwall:

- Invasive species control in the bench and riverward slope zones

- Thinning of willows planted at the toe, if necessary, to enable inspections
- Evaluate potential to incorporate large shade trees into riverward slopes of the project, especially if the Lower Green River Solar Radiation Priorities Map (prepared by the Muckleshoot Tribe in support of the Green River SWIF, 2013) indicates that the shoreline location is a shade tree priority
- Watering until plant establishment and noxious weed control
- Mowing the upper riverward slope for trail safety and to facilitate inspection

All PL 84-99 shorelines should be reviewed to identify if there are distinct shoreline locations that could be re-vegetated to address chronic riverward toe erosion and slumping of the riverward slope. This recommendation is consistent with a structural Interim Risk Reduction Measure that is proposed within Chapter 5 of this report.

## 4.7 PL 84-99 Vegetation Considerations and Guidelines

Lower Green River shoreline vegetation, in the vicinity of levees and floodwalls, should be designed and maintained consistent with the guidance presented within this chapter. Table 4.2 provides a detailed overview of each proposed Vegetation Management Zone according to these categories:

- Current vegetation conditions typically found within the vegetation management zone, as of 2015.
- Overview of risks and considerations associated with vegetation. Risks and considerations associated with vegetation are categorized by: structural integrity; inspectability; public use; water temperature; and habitat.
- Target vegetation structure and plant palette for the zone. This subsection provides an overview of the future desired vegetative condition for each vegetation management zone, taking into account the risks and considerations associated with that zone.
- Operations, maintenance and stewardship considerations for the zone. This subsection summarizes the maintenance guidelines associated with each PL 84-99 shoreline vegetation management zone, taking into account the risks and considerations, as well as the target vegetative structure and species associated with that zone.

Overarching considerations to guide SWIF implementation across all PL 84-99 shoreline vegetation management zones:

- Work with the USACE to ensure that continuing inspections take place in early spring, during low flow, prior to leaf out of vegetation.
- Work with the USACE to incorporate water based inspections, as part of the continuing inspections, to complement inspections by foot.
- Maximize space to support future capital project design, as feasible, that results in the levee or floodwall structure being placed as far landward as possible, to achieve stable slopes, sufficiently wide riverward benches, shallow sloping banks, large shoreline trees, recreational trails and other design considerations.
- In advance of implementing SWIF capital projects (Chapter 3), identify potential early action tree planting locations that would not compromise PL 84-99 levee integrity, in coordination with other parties working to improve the vegetated condition of the Lower Green River shoreline (e.g., WRIA 9, Muckleshoot Tribe, etc.).

**Table 4.2** PL 84-99 Shoreline Vegetation Management Zone Guidelines. This guidance is intended to serve as a starting point for each capital project design, maintenance and repair project that takes place in the vicinity of levees and floodwalls enrolled within the PL 84-99 program.

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| **VMZ 1: Landward Zone** | • Area landward from the landward toe of the levee<br>• VMZ 1 width is variable, as a function of land uses adjacent to the levee or floodwall.<br>• Includes a 15 foot wide inspection zone that runs along the landward side of the levee prism. In some location this 15 foot inspection zone may be set more landward of the levee to allow inspection of levee drainage systems.<br>• Dominated by residential and commercial landscaping, parking lots, parks, golf courses. | Levee integrity<br>• Vegetation in this VMZ should not impact levee stability<br>• Vegetation in 15' inspection zone could impede physical access or inspection, especially during emergency flood fights<br>Water Temperature<br>• Mature trees (100' height) within the shoreline zone could cast shade to river. With increased distance from river, though are expected to be less effective in casting shade to the river than trees established in riverward vegetation management zones.<br>Public Use<br>• Tall deciduous trees could drop limbs and leaf litter on the trail or adjacent properties.<br>• Dense mid-height vegetation could attract homeless encampments<br>• Internal drainage systems, sewer systems and sub-surface infrastructure may be impacted by vegetation planted in this zone.<br>Riparian Habitat<br>• Riparian habitat values in this VMZ are reduced by the distance from the water's edge and physical disconnection from other riparian habitat features, but native vegetation in this zone could provide microclimate, wildlife habitat, and erosion control benefits (per WRIA 9 scientific recommendations). | 15' inspection zone: In most cases this subzone will be maintained as a tree and shrub free zone to allow detection of seepage through the levee and to support emergency flood fight access. Shrubs should be kept at a minimum to allow detection of seepage.<br><br>Landward of 15' inspection zone:<br>• Tall 100'+ trees, maintained to support other public and adjacent land uses may be appropriate<br>• Intermediate height riparian trees<br>• If VMZ 1 is adjacent to open space that is not characterized by public or private land uses, it may be appropriate to incorporate | • Watering, weeding and ongoing control of invasive/noxious weeds<br>• Pre-flood season mowing in the 15 foot' inspection zone<br>• Prepare a tree management plan to guide tree limbing and hazard tree management and implement periodic inspections to comply with the tree management plan. |

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| | | | more trees, shrubs and other native vegetation. | |
| **VMZ 2: Landward Slope** | • Area from the landward toe/base of the levee to the landward edge of the levee crest<br>• Current vegetation in this VMZ is variable and typically reflects adjacent land uses, landscaping, and sometimes includes invasive species such as English Ivy, blackberry and reed canary grass. | Levee integrity<br>• Large trees located in this zone could pose a risk to levee integrity (blow downs, roots penetrating through the levee). A levee specific risk assessment will take into account location of the interior/minimum levee prism with respect to this VMZ. If sufficient depth of soil material is available, large trees and their roots are less likely to pose a risk to levee integrity.<br>• Large trees located in this VMZ that are established in material that is surplus to the minimum levee prism (Figure XX – in DRAFT Plan, not this summary matrix) should not pose a risk to levee integrity<br>• Downed and dead trees in the zones require root removal to minimize seepage<br>• Dense vegetation in this zone would limit inspection for sources of seepage, animal burrows and seepage during flood events.<br>Water Temperature<br>• Tall trees located in this VMZ (100' height or taller) may have the potential to cast shade to the main channel. In priority Shade Tree locations (see MIT Sun Map) the benefits associated with establishing some tall trees in conjunction with a systematic vegetation monitoring program, could outweigh the potential risks<br>Public Use<br>• Dense mid-height vegetation in this zone may increase public safety concerns, | • Upper 10 feet of the landward slope will be kept in a mowed state, to support of annual inspections, as well as to meet trail user safety needs.<br>• If levee geometry is appropriate with respect to slope as well as the location of the minimum levee prism within the overall as-built levee prism, some large shade tree species (target mature height of 100' or more) may be planted in this VMZ, as guided by the MIT Sun Map.<br>• Low density, low height shrubs may be established in this VMZ, so long as they do not | • Slope mower for the top 10 feet of the landward slope<br>• Watering, weeding and ongoing invasive plant management<br>• Hand brushing around trees and shrubs prior to inspections<br>• Removal of lower limbs of trees to allow inspection and provide visibility<br>• Ongoing hazard tree management |

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| | | especially when public trails are located on the top of levees<br>Riparian Habitat<br>• This VMZ is physically separate from the riparian zone by the levee crown, which typically contains an access road and/or recreational trail. Riparian vegetation has less value in this VMZ, given the physical disconnection from the shoreline. However, native vegetation in this zone could provide microclimate, wildlife habitat, and erosion control benefits (per WRIA 9 scientific recommendations). | spread creating dense thickets. | |
| **VMZ 3: Levee Crest** | • Variable width, flat, top of the levee, between the landward slope and the upper riverward slope<br>• Some existing landward and riverward slopes are gentle – hard to discern edge of levee crest<br>• Typically contains paved recreational trails and/or maintenance access roads. On the Dykstra levee, the levee crest is mostly an extension of adjacent residential lawns/landscaping.<br>• Typically contains a | Levee integrity<br>• Most if not all levee crests zones are too narrow to accommodate additional vegetation<br>• Trees and shrubs are not appropriate for this zone, due to root penetration and potential for large pits to be exposed at the root zone, if blown down. If levee crest is wide enough, it may be possible to plant trees which would not result in damage to the Corps minimum levee prism; this is the exception rather than the rule given relatively narrow widths for VMZ 3.<br>Water Temperature<br>• Though shade trees planted in this zone have a high potential to cast excellent shade to the main channel, the risks to levee integrity outweigh the benefits to water temp/quality unless the levee crest is overbuilt.<br>Public Use<br>• Recreational trail user safety and visibility may be impacted with mid-height shrubs in this zone. If VMZ3 levee crest is wide enough to support additional vegetation, planting | • Unless this zone is widened, as part of a levee setback or other capital project – this zone's target vegetation is grass shoulders adjacent to paved trails/roads or lawn. | • Control of invasive species<br>• Mechanical brushing/mowing of shoulders<br>• If crest is wide enough to support trees, ongoing limbing of trees for public safety and visual access<br>• Inspection and maintenance of hazard trees. |

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| | narrow band of herbaceous vegetation, invasive and noxious weeds, on each side of trail/road or maintained lawn. | plans shall result in sufficient visual sightlines for trail users.<br>Riparian Habitat<br>• This zone serves as a physical barrier to achieving connected riparian habitat, given its location between the riverward slope and the landward side of the levee.<br>• Native vegetation in this zone could provide benefits including microclimate, wildlife habitat, erosion control, and invertebrate prey input for fish. | | |
| **VMZ 4: Upper Riverward Slope** | • Size will vary but is typically the upper 1/3 to 2/3 of the entire levee's riverward slope, as measured from ordinary high water. Existing slope gradients for this VMZ vary from very steep (<2:1) to more gentle (3:1)<br>• Riverward extent of this VMZ may be defined, in some locations, by the presence of a riverward bench.<br>• Some repaired or rehabilitated levees contain dense, stands of native shrubs/plants that are over 10 years old, planted in | Levee integrity<br>• Large trees or tall shrubs planted in this zone may pose a risk to structural integrity (scour at roots at high flows – low probability but high risk) and may also limit visibility in support of levee inspections unless they are planted in areas surplus to the minimum levee prism<br>Water Temperature<br>• Shade trees (100' or taller) in this zone have the potential to shade the main channel and improve water temps/quality<br>• Slope gradient should be considered prior to planting large shade trees<br>Public Use<br>• Dense mid-height vegetation in this zone may limit visibility from the top of levee trail towards the river<br>Riparian Habitat<br>• This zone has the potential to contribute important structural elements (shade and cover) and functional (nutrients, organic supply, etc) riparian and riverine habitat needs.<br>Design Considerations | • Riverward vegetation management zones offer the best locations to improve riparian habitat and shade conditions. Yet, establishing large trees, shrubs and other native plant species in these areas may also compromise levee integrity and public safety if levee geometry is not taken into consideration. Target vegetative structure for this zone must be customized to reflect unique site conditions | • Installation/ removal of filter fabric sheet mulch on planting sites<br>• Watering, weeding and ongoing invasive species management<br>• Mowing of the upper XX feet of the upper riverward slope<br>• Limbing of lower branches of shade trees to allow inspection<br>• Ongoing |

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| | accordance with varying design guidelines in place at the time of construction.<br>• Outside of completed levee repair and rehabilitation projects, this VMZ typically contains invasive species and non-native vegetation | • The further landward the minimum levee core is built, the greater the depth of surplus soil on the upper riverward slope that can support trees that can be established to help meet temperature reduction objectives.<br>• The impact of vegetation on roughness and conveyance needs to be considered in the levee design and planting plan.<br>• Upper riverward slope vegetation height and density will need to be adjusted in some locations to allow views of the river.<br>• In order to make room for the creation of a riverward bench with sufficient width to support large tree planting, the slope of the upper riverward slope may need to be steeper than the target 3:1 slope. | (e.g. slope gradient, public access, etc.)<br>• With careful placement and ongoing maintenance/stewardship, large shade trees should be established in this zone, whenever possible<br>• In general, target vegetative structure for this zone will include the minimum necessary mowing to meet trail safety requirements and to facilitate inspection and careful incorporation of large shade trees and non-spreading shrubs spaced so that there is a minimum of 3 to 4 feet of grass/groundcover between mature shrubs. | inspection of trees for overall health and potential scour. |

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| **VMZ 5: Riverward Bench** | • This VMZ (riverward benches) may or may not be present along existing levees. Benches are formed by natural processes or intentional design as part of a capital project<br>• Benches formed by sand/silt deposits on over-steepened slopes often contribute to slope failure. These benches typically support dense stands of blackberry and reed canary grass<br>• Intentionally designed benches are level features that are typically planted with native shrub and tree species. These VMZs have typically been managed to allow the maximum possible growth of native vegetation.<br>• Future wider riverward benches are desirable to accommodate shade | <u>Levee integrity</u><br>• Vegetation in this zone has little to no effect to levee integrity<br>• Constructed benches are intended to support large trees and mature riparian vegetation<br>• Benches can also support inspection footpaths that can be brushed out prior to annual inspections<br><u>Water Temperature</u><br>• Constructed riverward benches offer ideal large shade tree planting locations due to level planting surfaces and proximity to the river.<br>• Current dense, vegetative conditions may limit rapid growth of trees (too much shade). Future vegetation management practices for this VMZ can address this.<br><u>Public Use</u><br>• Most benches are not accessed by the public, with the exception of some anglers and tribal fishers<br>• After 10+ years, in some locations, densely planted and unmaintained trees, shrubs and other native plantings on benches completely obscure views of the river from the levee crest/trail<br><u>Riparian Habitat</u><br>• This zone is the 2nd closest to the river's edge and offers excellent potential to establish multi-canopied (trees and shrubs) riparian vegetation which meets multiple habitat objectives (shade, high flow refuge for fish, invertebrate prey, microclimate, wildlife habitat, erosion control, wood supply, and nutrients).<br><u>Design Considerations for vegetation</u> | • Priority for this zone is to establish/maintain large shade trees<br>• Shrub species in this zone should be slow spreading and shade tolerant unless the bench is wide enough to allow the establishment of more complex communities without compromising inspection of the upper and lower riverward slopes via minimally maintained inspection trails.<br>• All tree and shrub species planted need to have hardy root systems that can sustain intermittent siltation/sedimentation from the river's depositional processes | • Installation and removal of fabric sheet mulch may be necessary on naturally occurring benches which have with well-established communities of invasive vegetation.<br>• Watering, weeding and ongoing invasive species management.<br>• Maintainance of one or more inspection foot paths on the bench. |

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| | trees in priority shade areas (MIT Sun Map) | • A bench located riverward of a levee or floodwall is the most effective and potentially least risky place to establish large shade trees. Design options include: establishing one wider bench; multiple benches at various heights; or instead of benches the design of but very gradually sloping banks that support trees and shrubs. Bench width should be maximized, as is feasible.<br>• If a launchable toe is to be installed beneath the riverward bench, the impact of the toe launch and destabilization of the riverward bench on the achievement of vegetation outcomes must be estimated and mitigated. Identifying the extent to which the toe launch will impact the bench should be considered when developing the vegetation plan for the site. It may be desirable to limit plantings in these areas to plants that have the greatest chance of adjusting to a changing surface.<br>• Benches must contain a sufficient depth of uncompacted soil over structural materials to allow vegetation establishment and growth.<br>• The impact of vegetation on roughness and conveyance need to be considered in the levee design and planting plan.<br>• Riverward bench vegetation height and density will need to be adjusted in some locations to support views of the river from the levee crest. | | |
| **VMZ 6: Lower Riverward Slope** | • Variable size, ranging between 1/3 to 2/3 of the levee's lower | <u>Levee integrity</u><br>• Trees planted in this zone have limited impact to levee integrity, as this zone is typically outside the minimum levee prism. | • Target vegetative structure of this zone depends upon whether a | • Watering, weeding and ongoing invasive |

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| | riverward face.<br>• Depending on the presence and elevation of a midslope bench (VMZ 5), it may be appropriate to use the bench to define the break between the upper and lower riverward slopes. Most areas in this zone currently dominated by blackberry and reed canary grass<br>• Some areas have been planted with willows, as part of levee repair capital projects. Willows overhang the river ~5 meters in less than a decade<br>• This zone is almost always too steep to travel by foot due to depositional and slumping processes | Large trees planted in this zone should not be installed directly above toe rock, due to risks associated with the tree falling and dislocating structural elements.<br>• Smaller, water tolerant riparian species (willows, dogwood, etc.) are more appropriately placed, in conjunction with toe rock<br>• Willows provide exceptional levee stability benefits, given their dense root structure, durability and fast growth<br>Water Temperature<br>• Willows and other smaller scale riparian species of this zone are typically fast growing and provide localized shade to the main channel<br>Public Use<br>• Willows often outcompete other planted riparian species and when leafed out, have the potential to create a 'willow wall' effect – effectively blocking all views of the river<br>Riparian Habitat<br>• Riparian plants, shrubs and smaller tree species in this zone are directly in contact with the river and its natural processes. Habitat benefits (structural and functional) are plentiful and include physical and visual protection from predators for salmonids, as well as insect leaf and drop to support the aquatic food chain. Shallow slow water in and adjacent to this area with wood and native vegetation provide optimal rearing habitat for juvenile salmonids.<br>Design Considerations<br>• Identify lower growing vegetation locations to support views of the river from the levee crest | bench is present and if so, its elevation<br>• Water tolerant riparian species (smaller trees and shrubs) able to thrive with occasional inundation and sedimentation/silt ation are appropriate for this zone<br>• At the extreme lower limit of this zone (10-15' from water's edge, up slope), willow and dogwood should be used almost exclusively<br>• Willow plantings should be intentional, in clumps, and interspersed with significant sized groupings of other water tolerant shrub/tree species (dogwood, etc.) that do not limit views of the river | species management<br>• Once established in appropriate locations, willow and dogwood species require limited to no maintenance |

| Veg. Manage-ment Zone (VMZ) | Description | Levee Integrity and Other +/- Considerations Associated with Vegetation in This VMZ | Target Vegetative Structure | Operations, Maintenance and Stewardship |
|---|---|---|---|---|
| | | • On existing PL 84-99 shorelines, ID vulnerable scour locations at the current riverward toe that would benefit from the structural stability of planting additional water tolerant shrub species, as outlined within Chapter 5 (IRRMs). | from the levee crest. | |

# Chapter 5 Interim Risk Reduction Measures

This chapter of the Green River System Wide Improvement Framework Interim Report summarizes primary Interim Risk Reduction Measures (IRRM) recommendations to reduce life safety risks posed by the Green River levee system while long-term solutions are being pursued through the Capital Plan.

Interim Risk Reduction Measures are structural and non-structural actions that reduce the likelihood and consequences associated with inundation risk landward of the levee systems, while long-term and comprehensive solutions are being planned and implemented (Corp of Engineers 2014). The SWIF Interim Report defines a provisional level of protection based on the likely consequences of flooding to public safety, infrastructure, current and future economic development, and projected cost of expected damages in the event of levee overtopping or failure. The interim risk reduction measures outlined within this chapter are a critically important part of the District's approach to reducing flood risks over time, prior to capital project implementation.

When establishing risk reduction measures, the prevention of loss of life is the highest priority, followed by prevention of high economic or environmental losses. IRRMs include both structural and non-structural components. Examples of structural risk reduction measures include: sand bags/bulk bags; temporary rock placement; overtopping resiliency features; erosion protection, and scour/erosion protection. Examples of ongoing non-structural risk reduction measures currently administered by King County include: flood warning and emergency evacuation plans; flood patrol program; comprehensive river and floodplain management plan; emergency response and public communication plans.

## 5.1 Flood Risks and Vulnerabilities

Preparation of the SWIF Interim Report was informed by an analysis of flood risks and vulnerabilities of the river and floodplain system, flood protection facilities and developed areas at risk of inundation. This technical study evaluated the geomorphic, geotechnical and hydraulic characteristics of the system, to better understand areas at risk in the Lower Green River Valley and how the current system of flood protection facilities function under different flood event scenarios.

Howard Hanson Dam and the Green River's system of levees and revetments are intended to work together to reduce flood risks to the Lower Green River and its valley. The Dam regulates outflows from the reservoir to 12,000 cfs at the Green River Auburn gage, at about river mile 31. Recent floods in King County occurred in November 1990, November 1995, February 1996, November 2006 and January 2009. Typical flood damage included undermining by scour along the toe of levees and revetments in the Lower Green River, slumping of banks and levee side slopes, and erosion of flood protection facilities. While these events ranged from the 10- to 100-year event on other King County rivers, the regulated flow of 12,000 cfs on the Green River meant that these flood events were the equivalent of a much smaller 2-year event pre-dam, but extended over a longer duration, placing stress on the Lower Green River levees.

The lower Green River Valley was developed with the general understanding that Howard Hanson Dam (HHD) provided 500-year containment and storage of floodwaters in the upper watershed. A 2012 USACE study concluded that HHD provides only 140-year containment. To inform SWIF Interim Report

preparation, a preliminary evaluation was completed of the potential to increase the capacity of HHD, through structural or operational approaches. This evaluation revealed that high costs, structural issues, and other feasibility challenges limit the potential or likelihood of the dam's future expansion to achieve additional storage. For additional detail, please see **Appendix F** (Howard Hanson Dam Evaluation). These findings place a greater importance on ensuring that downstream levees and flood facilities are functional and built to contemporary engineering standards. Also, if the region desires a 500-year level of protection, improvement and increased capacity of the flood protection facilities (levees and floodwalls) would be necessary.

A Geomorphic Assessment (Appendix B) indicated that between 1986 and 2011, stream bed erosion lowered the channel bed from one to two feet throughout the Lower Green River; greater incision has occurred on channel bends, with seven locations in the lower Green River with incision of five to ten feet or greater. An evaluation of levee repair locations showed that damage locations are typically located near channel bends and that when the channel bed has greater than five feet of incision there is a substantial risk of future damage to adjacent levees and revetments.

The SWIF Interim Report Geotechnical Assessment (Appendix C) reviewed previous levee stability studies and confirmed that existing levees are vulnerable to failure and require regular maintenance to reduce flood risks. Portions of the levees do not meet USACE recommended Factors of Safety (FOS), a common measure of engineering safety. USACE Factor of Safety criteria vary from a minimum required value of 1.0 to 1.6. Some Lower Green River levees have FOS values of 0.6 or less, while some have a FOS of up to 1.7 or higher. Potential levee failure modes that are common to the Lower Green River system of flood protection include: rapid drawdown, seismic, and under-seepage. Rapid drawdown conditions occur when river levels drop rapidly after sustained high water levels. The resulting saturated levee conditions are less stable and subject to failure. Under-seepage is the movement of water through the levee and its foundation, from the riverward to the landward side of the levee. Seismic failure occurs when either ground shaking directly damages levees or when saturated soils liquefy due to earthquakes.

The Green River flood model was updated to reflect current flood facility conditions, in support of completing the SWIF Interim Report's Hydraulic Assessment (Appendix D). This study revealed that current Lower Green River levees and existing unarmored shorelines provide variable levels of protection. Bank overtopping/inundation take place in some locations during a 2-year or 9,000 cubic feet per second (cfs) event while other armored shoreline locations are protected to upwards of 18,800 cfs, which is the SWIF Interim Report's metric for the 500-year level of protection. The river channel conveyance capacity for flows over the 12,600 cfs (median 200 –year flood event) and the extent and depth of inundation of the floodplain and developed areas vary widely depending on the levees and floodplain conditions. The modeled damage areas included Auburn (left bank, upstream), Tukwila (left bank, downstream), and Kent/Renton (right bank). More detail is found in the Hydraulic Technical Memorandum (Appendix D). **Figure 5.1** presents a composite of shoreline overtopping scenarios, generated from running the Green River Flood Model, using different flow rate scenarios.

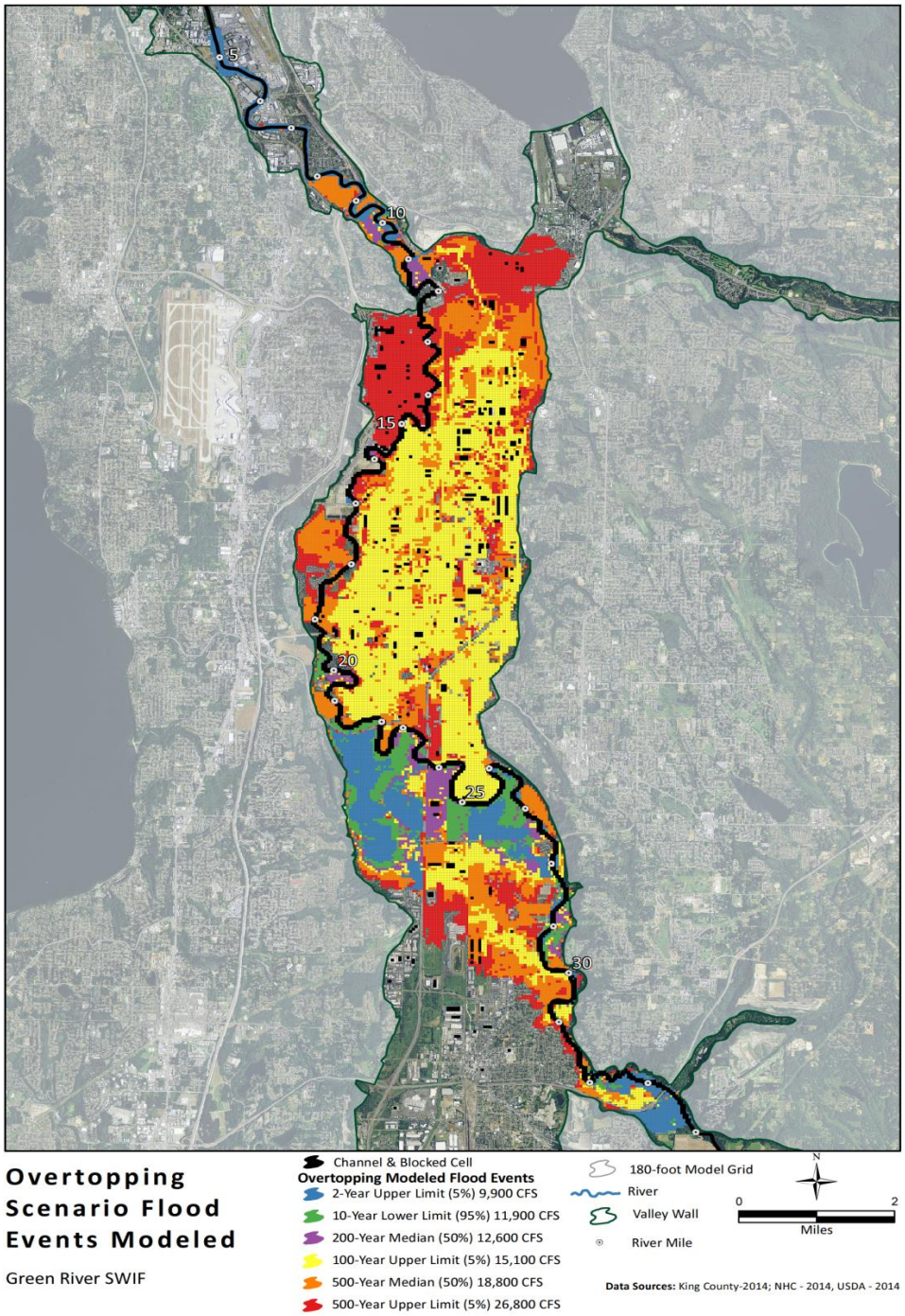


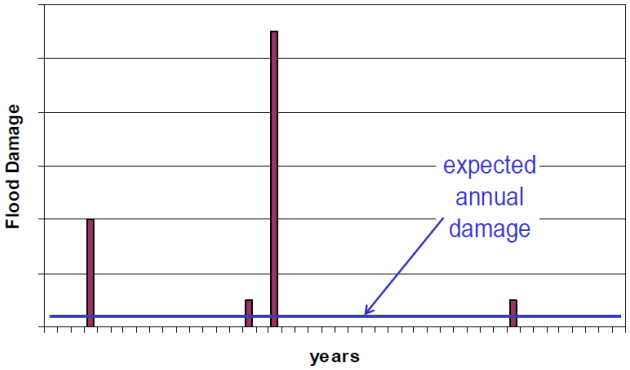

**Figure 5.1. Green River Flood Model Results for Variable Flow Rates**[1]

[1] Flow rates are shown for different recurrence intervals (10, 100, 200, 500-year), which are related to the percent chance of occurrence of a flood event in any given year (10, 1, 0.5, 0.2 percent). The 5, 50, and 95% shown in parentheses represent the 5% or 95% confidence limits, or 50% (median) estimate. The greater the flood, the more area inundated. For a 12,600 cfs flow event (200-year, median estimate), the blue, green and purple areas would be inundated. For an 18,800 cfs flow event (500-year, median), the yellow and orange areas would also be inundated.

## 5.2 Potential Levee Failure Modes

The USACE requires that an IRRM Plan be informed by an evaluation of four types of levee failures, including: (1) levee breach prior to overtopping, (2) levee overtopping with breach, (3) malfunction of levee system components, and (4) levee overtopping without breach. The following sub-sections describe each failure mode, and possible consequences, as they relate to the system of Lower Green River levees.

To aid in the evaluation of levee failure scenarios, a map of potential damage areas was developed for the Lower Green River valley (Figure **5.2**). These mapped potential damage areas follow logical divisions in levee systems and flood patterns. Four levee failure scenarios were developed and modeled, using the Green River Flood Model, to reflect a full range of flows (or flood events) with different probabilities of occurrence in any given year. Next, estimates of flood damages corresponding to various levels of flooding in the valley were prepared (Appendix E); these flood damage cost estimates were converted to an estimate of "expected annual flood damages". Expected annual damage (EAD) is the average annual damage expected over a long period of time. It is based on the probability of different magnitude flood events and the associated damages that are estimated to occur. EAD is estimated because the natural variability in flood events prevents us from knowing what the actual future damages will be.



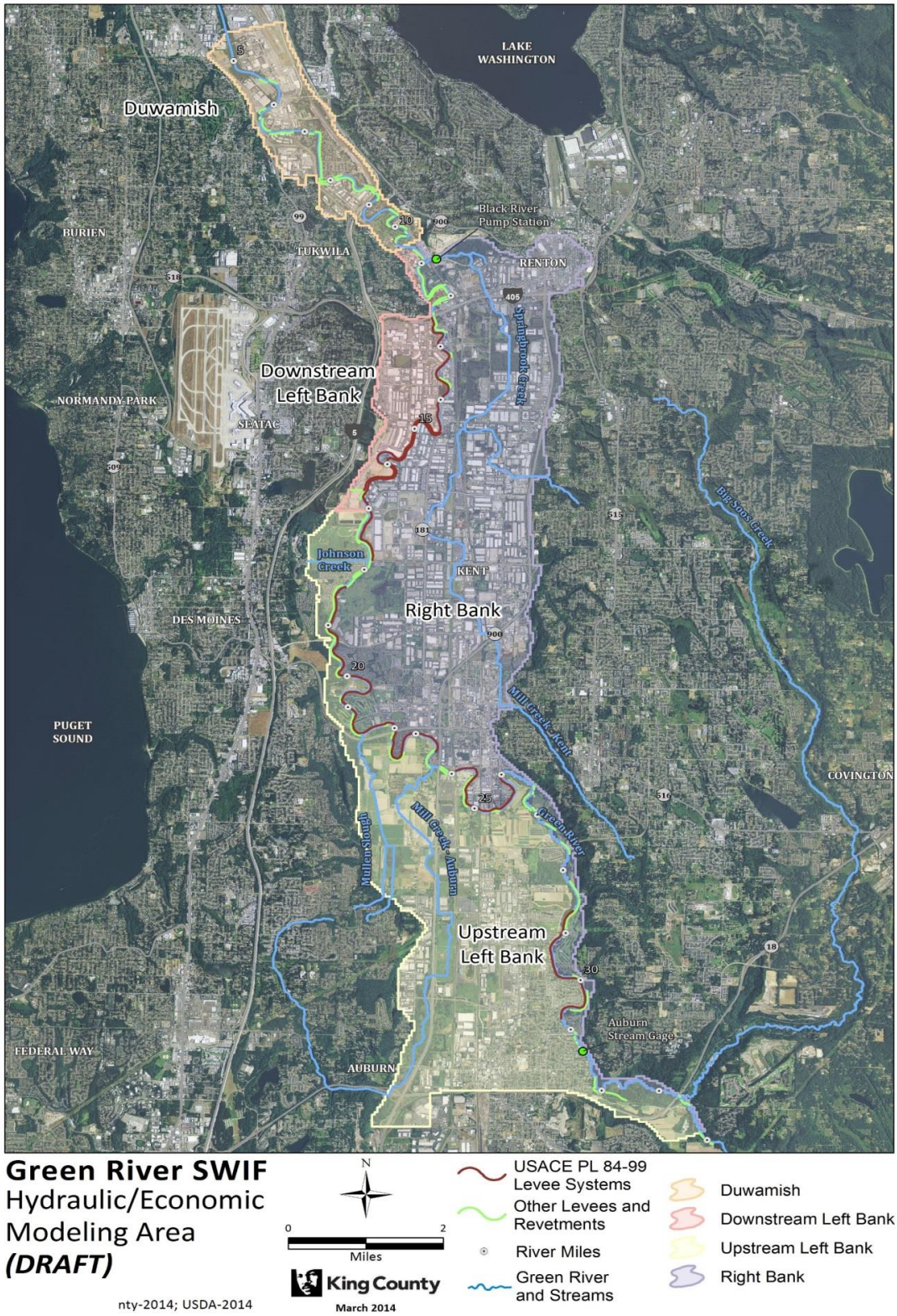



**Figure 5.2. Lower Green River Economic Damage Areas**

### 5.2.1 *Levee Breach Prior to Overtopping* Failure Mode

Breach prior to overtopping refers to a general levee failure where either levee erosion or another type of structural failure occurs. This failure mode reflects the assumption that levees will breach when the water surface is below the crest of the levee.

This failure mode was explicitly analyzed and modeled as part of the existing condition analysis (Appendix E). Four potential levee breach locations were identified, following a review of geotechnical, geomorphic, hydraulic and economic factors. Geotechnical analysis at each potential levee breach location showed that the probability of geotechnical failure at lower river stages (within 1 foot of the landside levee toe) was fairly low, varying from 0.1 to 2 percent. At higher stages, when the river stage was near the levee crest, the composite probability of failure varied from 0.2 to 6 percent. The presence of deficiencies may result in a higher potential for premature breach.

The EAD for the breach prior to overtopping levee failure scenario was estimated at $48.4M, assuming potential breaches in the upstream left bank and downstream left bank damage areas. With breaches along the right bank damage area, EAD estimates ranged from $42.8M to $50.0M per year.

### 5.2.2 *Overtopping with Levee Breach* Failure Mode

The overtopping with levee breach scenario starts as an overtopping event (i.e. when floodwaters exceed channel capacity), followed by a levee breach caused by the overtopping. This failure mode was not analyzed and modeled as part of the SWIF Interim Report Current Conditions Report. Instead, a composite of the existing condition flood modeling results, from each of the breach model runs, was created as described below:

- For the 15,100 cfs event, there is no overtopping into the Auburn or Tukwila damage areas, only overtopping into the Kent/Renton damage area. Therefore, only the Meyers Golf and Horseshoe Bend breach depth grids were averaged, and the results only applied to the Kent/Renton Damage Area.
- For the 18,800 cfs event, overtopping occurred into the Auburn and Kent/Renton Damage Areas, but not the Tukwila damage area. All three breach scenarios (Dykstra/Tukwila, Horseshoe Bend and Meyers Golf) were averaged. Only the Auburn and Kent/Renton damage areas had composite grids applied. The Tukwila damage area did not overtop.
- The 26,800 cfs event overtops into all damage areas.

Based on the geotechnical, geomorphic, and hydraulic analyses completed for the existing condition analysis, the probability of levee breach following overtopping is very high and it is estimated that there is a 100% probability of breach at overtopping for all four of the potential breach locations. The system-wide expected annual damages for the overtopping with breach scenario was estimated to be $44.7M.

### 5.2.3 *Malfunction of Levee System Components* Failure Mode

Malfunctioning of levee system components, assuming no levee overtopping, would result in the least amount of consequences of the four failure modes. Within the levee system, the components likely to malfunction are interior drainage pipes flap gates or failure of pump stations designed to pump interior drainage into the Green River during the flood event. This failure mode was not modeled or analyzed as part of the Current Conditions Report. However, nearly all the pipe and culvert levee penetrations, as well as flap gates, identified as PL 84-99 deficiencies are currently being evaluated and/or resolved through Deficiency Action Plan implementation.

### 5.2.4 *Overtopping Without Levee Breach* Failure Mode

Levee overtopping without a levee breach is the least likely failure mode evaluated. The original levees were constructed in the 1960s, using material excavated from the river bed, without compaction control. Thus, subsurface soils within the levee prism typically consist of loose to medium dense silty sand that is vulnerable to erosion during an overtopping flood event. Therefore, the consensus of the consultants and project team is that the levees are much more likely to breach, than to remain intact when overtopped. Since construction of the levees and post Howard Hanson Dam construction in 1962, there have been no reported occurrences of levee overtopping or breaches. For reference, the peak flood flow during the past 53 years was 12,400 cfs at Auburn in February 1996.

This levee failure scenario was analyzed and modeled as part of the Current Conditions Report using three flood events: 15,100 cubic feet per second (cfs); 18,800 cfs; and 26,800 cfs. Flood modeling results noted that for flows which overtopped the levee, depths without breach are generally a few tenths of a foot less than in the overtopping with breach scenario. The consequences are less severe than for the overtopping with breach scenario.

## 5.3 People, Land Uses and Economies at Risk

People, homes and businesses are at risk from flooding in the Lower Green River Valley. Collectively, these assets serve as a vital economic engine for the region and state. Industrial, commercial, and residential development located in the cities of Kent, Auburn, Renton and Tukwila are subject to flood risks, as well as very significant infrastructure comprised of state highways, railroads, local roads and utilities. A snapshot of what is at risk in the Lower Green River Valley from flooding includes:

- 22,000 residents living in portions of the valley that may be inundated from a 500-year flood event
- $7.3 billion in floodplain structures and contents
- 100,000+ jobs (REI Corporate Offices, Boeing, Amazon Fulfillment Center, Starbucks Roasting Plant and many other small, intermediate and larger sized companies)
- 100 million sf warehouse + distribution space (2nd largest on West Coast)
- Comprises 1/8th of the GDP for WA State, with an annual taxable revenue of $8 billion

The potential impacts of major flooding to people, communities, structures, infrastructure, businesses and jobs in the Lower Green River could be substantial. With a 500-year flood event (18,800 cfs), approximately 7400 acres of the valley would be inundated from <1 to 6-10 or more feet in depth. This area of potential inundation was further analyzed to better understand the total number of people and types of structures possibly affected (**Tables 5.1** and **5.2**).

**Table 5.1. Total # residents within potential inundation areas associated with a 500 year flood event (data sources: Green River Flood Model; 2010 Census Block Info)**

| RACE | Population #s | under 18 | 18-65 | 65 or older |
|---|---|---|---|---|
| **White** | **12660** | 2004 | 8558 | 2098 |
| **Black/African American** | **2391** | 666 | 1639 | 86 |
| **Native American or Alaskan Native** | **304** | 80 | 203 | 21 |
| **Asian** | **1916** | 404 | 1354 | 158 |
| **Native Hawaiian or Pacific Islander** | **639** | 233 | 394 | 12 |
| **Other** | **2511** | 888 | 1578 | 45 |
| **Two or More** | **2278** | 668 | 1578 | 32 |
| **Total # residents** | **22,699** | **4,943** | **15,304** | **2,452** |

The area of inundation that may result from levee overtopping, as a result of a 500 year flood event, was further examined using the Flood Damages Assessment model to estimate system-wide expected annual damages over a period of 50 years. With a 500 year flood event (18,800 cfs), the damages and impacts to residential, commercial, and public structures and contents, vehicles, post-flood cleanup, utility repairs, crop losses and lost recreation value, and reduced output (sales/gross revenue) from closures of businesses following inundation was estimated at $47.1 million/year. As economic recovery progresses following a flood event, this estimate of annual damages is expected to decrease with time.

In addition to the commercial, industrial and other land uses that contribute to regional and state-wide economic health, the valley also contains single and multi-family residences, mobile homes, apartments and condominiums. **Table 2** summarizes the number of structures, by type, in the floodplain. The structure counts are presented according to four economic modeling damage areas that were used to assess risks of levee overtopping and breaching (e.g., levee failure). For additional information, please see the SWIF Interim Report Current Conditions Reports (**Appendices A-E**) and the SWIF Interim Report Interim Risk Reduction Measures Plan.

**Table 5.2 – Structures in the Floodplain**

| Analysis Unit | Number of Structures by Type | | | |
|---|---|---|---|---|
| | Residential | Commercial | Industrial | Other* |
| **Auburn (Upstream Left Bank: RM 17 – RM34)** | 3,484 | 873 | 74 | 72 |
| **Tukwila (Downstream Left Bank: RM10.5 – RM17)** | 30 | 273 | 13 | 3 |
| **Kent/Renton (Right Bank: RM10.5 to RM34)** | 1,266 | 1,769 | 178 | 44 |
| **Duwamish (Downstream: RM4.5 to RM10.5)** | 591 | 196 | 36 | 6 |
| **Sub-Total** | **5,371** | **3,111** | **301** | **125** |
| **TOTAL** | | **8,908** | | |

Other land use types and resources at risk from flooding include farms and regionally significant agricultural resources located within the unincorporated King County portion of the project area. The King County Lower Green Agricultural Production District (APD) is located along the left bank of the river and consists of about 1,400 acres of prime soil, split into two separate areas. Approximately 75 percent of the Lower Green APD is in the King County Farmland Preservation Program which purchased the development rights for these properties.

Recreational resources in the project area include city owned parks, natural areas and local trails. King County maintains multiple use regional trails within the project area, including the Green River Trail, which travels along significant portions of the right bank shoreline of the Lower Green River. Though no comprehensive recreational use studies have been completed for the project area, across jurisdictions, these recreational assets are used by local residents as well as recreationists who live outside of the project area.

## 5.4 Existing Flood Risk Management Plans

This section provides a brief description of three planning documents, prepared by King County, which informed preparation of the IRRM Plan: the Deficiency Action Plan; the King County Flood Hazard Management Plan; and the Regional Hazard Mitigation Plan.

### Green River Levee Deficiency Action Plan

The Levee Deficiency Action Plan (DAP) is a foundation document for the Green River System Wide Improvement Framework. The DAP addresses the deficiencies identified by the USACE for the twelve PL 84-99 levee segments. The DAP submittal, as outlined in Chapter 2, summarizes actions the King County Flood Control District has taken or will take to correct deficiencies.

### King County Flood Hazard Management Plan Update (2013)

The National Flood Insurance Program's Community Rating System requires an update every five years to King County's Flood Hazard Management Plan. The 2006 King County Flood Hazard Management Plan recommended regional policies, programs, and projects to reduce the risk to people and property from river flooding and channel migration in King County. Whenever possible, recommended flood hazard management actions seek to reduce flood and channel migration risks while protecting, restoring, or enhancing riparian and aquatic ecosystems. The 2013 Flood Hazard Management Plan Update represents an update to the 2006 King County Flood Plan, to account for new information on hazards, vulnerabilities, accomplishments, and proposed actions for major river and floodplain management activities. The 2013 Plan includes flood risk reduction efforts centered on five basic strategies:

- Updating, collecting and managing flood hazard information
- Regulate, where appropriate, the creation of new flood risks and to promote flood-tolerant structures
- Maintaining river channels
- Managing flood facilities
- Providing flood hazard education, promoting flood preparedness and improving flood warning and emergency response.

The 2013 King County Flood Plan Update maintains the County's Class Two rating in the federal Community Rating System program, which provides a discount of up to forty percent on federally backed flood insurance premiums for unincorporated King County property owners.

### King County Regional Hazard Mitigation Plan Update (2014)

Hazard mitigation is the use of policies, programs, projects, and other activities to alleviate harm to people, injury, and property damage that can result from a disaster. King County and a partnership of local governments have developed and maintained a regional hazard mitigation plan to reduce risks

from natural disasters. The plan complies with hazard mitigation planning requirements to maintain eligibility for funding under Federal Emergency Management Agency grant programs.

## 5.5 Interim Measures to Reduce Flood Risks

The goal of IRRMs is to reduce the risk of levee failure and catastrophic losses in the event of levee failure. IRRMs include emergency measures that are implemented during a flood event as well as measures implemented in advance of a flood event. In establishing IRRMs, the prevention of loss of life is the highest priority, followed by prevention of high economic or environmental losses. The King County Flood Control District funds and administers a comprehensive set of flood hazard management projects and programs that are intended to reduce risk to people, economy and environmental losses.

Following the convention of USACE guidance, IRRMs are presented using two categories: structural and non-structural. Many of the identified IRRMs currently exist and are incorporated within the District's operating budget. There is an important connection between unresolved PL 84-99 deficiencies (see Chapter 2) and IRRMs. Unresolved deficiencies that are in the process of being corrected and/or monitored may require an IRRM in advance, during or after a flood. For example, if a culvert or other type of levee penetration deficiency has yet to be resolved, it may be appropriate to target flood patrols, site scale monitoring during a flood event, or other interim measures to ensure that the unresolved deficiency does not serve as a driver for increased flood risks. Table **5.3** provides a summary of all Green River SWIF Interim Report IRRMs and whether each measure is an existing measure or newly proposed. The remainder of this chapter section provides a greater level of detail for each structural and non-structural risk reduction measure.

**Table 5.3. Green River SWIF Interim Report Interim Risk Reduction Measures Summary Table**

| Interim Risk Reduction Measure Name | Structural (S) or Non-Structural (NS) Measure? | Existing or new measure? |
|---|---|---|
| **1. King County Flood Warning Center and Program** | NS | Existing |
| **2. King County Flood Patrol and Levee Inspection Program** | NS | Existing |
| **3. King County Flood Hazard Management Plan** | NS | Existing |
| **4. Public Communication Program: preparedness, education, and understanding of residual risk** | NS | Existing |
| **5. Emergency Response (Post Flood Recovery) Program** | NS | Existing |
| **6. Animal Burrow Response Plan (Includes Pilot)** | NS | New |
| **7. Technical Studies, Assistance and Consultation** | NS | Existing |
| **8. Flood Hazard Area Regulations** | NS | Existing |
| **9. Effectiveness Monitoring To Improve Performance** | NS | New |
| **10. Sandbags** | S | Existing |
| **11. Bulk Bags** | S | Existing |
| **12. Earthen Levee Raising (Low Spots)** | S | New |
| **13. Small Capital Projects for Scour & Erosion** | S | Existing |
| **14. Temporary Rock Placement** | S | Existing |

### 5.5.1 Non-Structural Interim Flood Risk Reduction Measures

Non-structural risk reduction measures are intended to reduce inundation risks posed by flooding in the valley, while long-term solutions are pursued in support of improved public safety and fewer economic and environmental consequences. Many of King County's non-structural risk reduction measures are programmatic and implemented on a County-wide scale. A newly proposed, non-structural measure,

preparation and implementation of an Animal Burrow mitigation plan will be piloted in the Lower Green River. This section of Chapter 5 provides an overview for each nonstructural IRRM proposed. King County administers a comprehensive emergency response program (Table 5.4) and many nonstructural flood risk reduction measures are critical elements of that program.

**Table 5.4.** Emergency Response Program Elements

| Program Element | Description |
|---|---|
| **Communication Program: Flood Hazard Education, Flood Preparedness** | • **King County conducts public education and outreach on flooding issues in conjunction with area cities, local residents, and provides risk and emergency response information.** |
| **Flood Warning Program** | • **King County operates the Flood Warning Center and Emergency Coordination Center to provide information to municipalities in conjunction with USACE information from Howard Hanson Dam and the National Weather Service**<br>• **The Flood Warning Center operates under a four-phase response system based on Green River flow at the Auburn gage**<br>• **Reverse 911 systems are available through King County and Green River cities**<br>• **King County provides financial support to the U.S. Geological Survey for maintenance and operation of a river gage network** |
| **Emergency Response Actions** | • **The USACE has a dam safety and emergency response plan in place for Howard Hanson Dam**<br>• **King County staff may begin patrolling flood control facilities at Phase III King County may make available sandbags to citizens** |
| **Emergency Evacuation** | • **Evacuation routes have been designated and road signage installed**<br>• **Cities individually make the decision when to evacuate.** |

## King County Flood Warning Program and Flood Warning Center

The Flood Warning Program coordinates with local, state, and federal emergency warning and evacuation systems, including King County Office of Emergency Management, King County Sheriff's Department, the Road Services Division, local jurisdictions and other agencies to obtain and share up-to-date information about major flood risks, road closures, evacuations and other emergency services. Ongoing coordination also occurs with the USACE regarding dam operations and effects on flood flows within the Green River system.

The Flood Warning Center is the location of operations for the Flood Warning Program during flood events. King County's flood warning program includes a four-phase warning and alert system. The program warns residents and agencies of impending floodwater levels so they can take action before serious flood damage occurs. When high water conditions are imminent, King County activates its Flood Warning Center, operation of which is based on a four-phase warning system. Flood phases reflect cubic feet of water per second (cfs) and are taken at the Auburn gage near Lower Green River Mile 31.

- Phase I – 5,000 CFS
- Phase II – 7,000 CFS
- Phase III – 9,000 CFS
- Phase IV – 12,000+ CFS

Flood phase information is updated online http://green2.kingcounty.gov/RiverGageData/gage-data.aspx. River gages are monitored by King County staff on a 24-hour basis. At increasing phases, activities are triggered, including field inspection teams (flood patrols), press releases via local broadcasting media as well as county websites and social media. It also includes an opt-in phone/email/text message alert system. Early flood warning notifications are critical in providing additional time for property owners, floodplain occupants and those responsible for their safety to respond to flood threats. The Flood Alert System is implemented to simultaneously send voice calls, text messages and emails.

### King County Flood Patrol and Levee Inspection Program

King County on behalf of the District inspects levees annually during low water conditions to monitor and assess levee conditions. King County also receives and investigates complaints about flooding, channel migration, severe bank erosion and logjams on a year-round basis, especially during and immediately following flood events.

During flood events, King County deploys patrol teams to monitor river conditions. The primary emphasis is to monitor levee system performance, but they also monitor conditions at other locations, sometimes in response to citizen complaints. Patrol teams are trained to recognize situations that warrant emergency action to preserve levee system function or reduce flood risk. During large floods, two-person teams patrol flooded areas along the major rivers to provide rapid response to flooding complaints and evaluate whether logjams pose an imminent threat to public safety and/or public facilities. Patrols inspect County river facilities for structural damage and other warning signs that indicate potential facility failure that could adversely impact developed property.

### Public Communication: flood preparedness, education and risk information

King County on behalf of the District runs a flood hazard and flood preparedness outreach/education program which provides information to the community, including:

- Annual distribution of flood warning information and preparedness brochures that features flood warning and emergency response services, flood phase explanations, flood insurance and personal preparedness information, and important contact numbers and web addresses for additional information and assistance;
- Annual outreach to repetitive loss properties and floodplain residents via informational letters and flood warning information brochures;
- An up-to-date website (www.kingcounty.gov/flood) which hosts extensive and detailed information about flood warning, safety, and preparedness; local flooding conditions; flood mitigation programs; flood mapping information; and flooding documents;
- Public television and social media campaigns to announce flood preparedness information and services and special emergency conditions
- Outreach to vulnerable and underserved populations with on-call interpretation services, and flood preparedness and safety videos available in over 20 languages; and
- Encourage all businesses and residents in low-lying areas near rivers, regardless of levee accreditation, to purchase flood insurance.

## Emergency Response (Post Flood Recovery) Program

King County's Emergency Response Program is designed to be invoked following a disaster. A presidential major disaster declaration authorizes a wide range of programs for recovery, including financial assistance to public agencies, loans for individuals, families and small businesses, loans for farmers and ranchers, financial assistance grants, and housing grants. Major disaster assistance is provided through regional FEMA centers and the state. Since 1990, there have been 12 federal disaster declarations related to flooding.

A secondary component of the County's Emergency Response Plan is the post-flood recovery program. The recovery process includes immediate actions, such as recording high water marks, debris removal, and conducting inspections, and longer term actions such as seeking financial assistance and making repairs. All of these actions are necessary to assess damage, restore services and make repairs quickly. Several King County departments play a role in post-flood recovery, with much of the overall coordination provided by the King County Office of Emergency Management. Actions that King County may take or assist with to help minimize flood damage include:

- Inspecting flood protection facilities to identify damage during and after major flood events;
- Repairing damaged flood protection facilities that must be repaired as emergency actions before or during a flood event, or soon after floodwaters have receded;
- Staging of flood-fighting materials and equipment near potential areas of concern. For example, FCD 2013-02 requires King County to provide emergency materials and equipment for floodwall installations protecting highly developed areas in the City of Kent;
- Providing information to flood response agencies engaged in flood fighting and evacuations; and
- Making flood and flood fighting information and flood fighting materials available.

Precautions that citizens can take to avoid or reduce flood emergency damage and risk include: evacuation, avoiding flooded roads, moving possessions and livestock to higher elevations, and building temporary sandbag walls to keep floodwaters out of homes and structures.

## Animal Burrow Response Plan

An Animal Burrow Response paper was prepared in response to the USACE recommendation to develop and implement an animal control program that eliminates burrowing animals from levee embankments in Green River levees. The purpose of the report was to provide managers and USACE staff with an update on efforts to better understand the nature and risks associated with animal burrows on levees. The report serves as a preliminary report on a pilot program that the District has undertaken to better understand and respond to the 39 animal burrow deficiencies identified by the USACE. The recommendation is to continue the pilot program into early 2016 with the goal of developing an appropriate response by April 2016. This response would then be incorporated into an *Animal Burrow Mitigation Plan* for the District by the end of 2016. The pilot program includes the following elements:

- Continue removal of non-native landward slope vegetation to locate animal burrows and other possible sources of leakage.
- Refine inspection and documentation procedures and secure resources to do these inspections.
- Complete the literature review begun in 2014 and expand it to include review of other animal burrow programs.

- Develop risk assessment and site prioritization procedures, and use procedures to evaluate data collected under item #2.
- Obtain information on additional control methods identified but not yet researched.
- If control is determined to be warranted, implement a limited-scope program of up to 10 sites.
- Expand the pilot program if necessary to research the burrowing habits of other species. Use the information gathered in the course of the pilot project to inform the development of *Animal Burrow Mitigation Plan* for District levees.
- Identify and quantify the resources needed to implement the *Animal Burrow Mitigation Plan* and use these data to evaluate this need against other levee safety needs.

### Technical Studies, Assistance and Consultation

The District proposes one new technical study to support targeted and effective deployment of several structural risk reduction measures, as outlined within the next section. As an early implementation action item, the District will prepare a set of maps that summarize known low points in the levee system; levee toe locations that are vulnerable to scour and erosive riverine processes; and locations landward of each landward system that may benefit from interim flood proofing measures. These maps will be updated periodically to account for new information and changed conditions, to ensure that structural risk reduction measures can be targeted and effective. The District will share this information with local cities and other agency partners to improve inter-agency coordination and effectiveness. Critical infrastructure, located landward of the Lower Green River levee system, will be included on these maps to guide bulk bag placement and improved flood resiliency for local and regionally significant infrastructure assets.

King County currently offers technical assistance and consultation to public and private entities to make informed land use decisions that result in reduced flood related risks. King County's wide range of technical assistance and consultation services to the public include: sharing expertise in hazard identification techniques; interpreting flood hazard data, maps, and regulations; and reviewing and coordinating planning and design efforts by public and private entities that overlap, impact or are impacted by flood hazard areas.

### Effectiveness Monitoring To Improve Performance

King County on behalf of the District completed a pilot levee repair effectiveness monitoring study, "Lower Green River Levee Repair Retrospective" (2014). This information informed preparation of the SWIF Interim Report and will inform development of a comprehensive flood risk reduction effectiveness monitoring program. Effectiveness monitoring will evaluate three facets of the Green River SWIF Interim Report: (1) floodwall and levee performance over time; (2) shoreline trees and levee/floodwall performance; and (3) scour and slope failure rates. A variety of geotechnical/hydraulic levee designs and repairs along the Green River will be assessed over time to inform an adaptive management approach to SWIF Interim Report updates and management of the river and its flood protection facilities. This targeted monitoring program will identify primary successes and limitations in levee/floodwall designs and management to inform ways to improve performance. This nonstructural risk reduction measure was a recommendation in the Green River External Advisory Review Panel Report (Tetra Tech 2010).

### 5.5.2 Structural Interim Flood Risk Reduction Measures

Five structural Interim Risk Reduction Measures are proposed for the Lower Green River levee system, one of which is a newly proposed risk reduction measure and four that are currently part of the Flood Control District's approach to structural flood risk reduction. This section of Chapter 6 provides a short summary of each measure.

#### Sandbags

The District provides sand, sandbags and funds to cities that wish to set up sandbag distribution locations within their jurisdictions. Materials are stored at sites within ten miles of the Green River and can be transported quickly to the river. The Lower Green River cities of Tukwila, Kent and Auburn participate in this program and are responsible for notifying residents about sandbag availability. Placement of sandbags can help protect structures and infrastructure from floodwater inundation. As part of SWIF Interim Report implementation, King County will develop a map of known low points along the Lower Green River levee system that will be updated periodically. Public facilities suitable for sandbag storage will be evaluated for their proximity to areas of concern.

#### Bulk Bags (Temporary Increase in Levee Height or as Containment)

Bulk Bags (common industry name includes 'hescos' and 'super sacks') are oversized sandbags that can be placed along the levee crest and at low points, temporarily providing increased levee height and reducing risk of levee overtopping. They can also be used behind levees to create containment areas if there is concern of flooding in a specific location.

Bulk Bags were used along the Green River in response to the increased risk of flooding due to the limited storage capacity of the Howard Hanson reservoir while the dam was being assessed and repaired following the January 2009 flood event. They were put into place along 26 miles of Green River levees and remained in place until after the 2013 flood season.

A related non-structural risk reduction measure (as described within Nonstructural/Technical Studies portion of this IRRM Plan) is preparation of maps to identify key locations landward of existing levees and floodwalls that, in the event of levee breach or overtopping, would be protected with emergency placement of bulk bags.

#### Earthen Levee Raising to Prevent Overtopping

Forthcoming technical map products, to be produced as an early SWIF Interim Report implementation action item, will identify locations where small increases in levee height, with accompanying levee width adjustments as needed, could provide incremental increases in channel capacity and prevent overtopping. Depending on the scope, earthen levee raising can be implemented in less than one year assuming no in-water work with accompanying permits and compliance, are needed. Earthen levee raising is only feasible where the existing riverward side slope is relatively stable and where there is existing land available on the landward side. Each earthen levee raising project will require a structural analysis as part of the design to ensure that the extra weight cause by adding levee material does not add to instability of the existing levee.

#### Small Capital Projects to Protect from Toe Scour, Erosion and Slumping

As an implementation action, the District will identify locations where toe scour, erosion, and slumping are an emergent problem that can be resolved proactively, to avoid a PL 84-99 deficiency determination.

Some PL 84-99 shoreline locations would benefit from a small capital project to address steep, scouring, undercut, and slumping riverside toe areas. Small site scale capital projects may incorporate instream piling buttress, soil arching reinforcements, or rock placement if necessary for scour protection. Steep, slumping lower embankment zones may be reinforced with live cuttings driven in one or more rows, and supplemented with water tolerant tree plantings in this zone, such as Oregon Ash.

### Temporary Rock Placement, as Part of a Flood Fight

Response activities during a flood event or high water episode are expected to continue and therefore have been included as an IRRM. A rapid response including placement of temporary rock to address scour or levee slumping is sometimes necessary to protect homes, businesses and infrastructure. These emergency activities would be expected to continue as part of the IRRM Plan. Materials and crews for this work are available through the King County Roads Maintenance Section or private contractors and can be mobilized within hours if necessary. In the event these crews are already working at capacity during a flood event, on-call contractors can be brought in to supplement the workload. In the event all County resources are fully maximized, USACE flood-fighting response can be mobilized during a flood emergency as well.

## 5.6 Assessment of Interim Risk Reduction Measures & Recommendations

Interim Risk Reduction Measures represent an important step in an ongoing, adaptive risk management process that recognizes the dynamic nature of the sources of inundation risk. Prevention of loss of life is paramount, followed by the prevention of losses to economic and ecological resources. The attributes of each levee system are unique and the mix of risk reduction measures appropriate to each levee will vary, should the levee not function as designed.

All structural and nonstructural risk reduction measures were evaluated according to USACE defined IRRM evaluation criteria (USACE Engineering and Construction Bulletin 2014-2) for the purpose of establishing relative priorities between risk reduction measures. Table **5.5** summarizes the results of this evaluation.

**Table 5.5. Lower Green River Interim Risk Reduction Measure (IRRM) Evaluation Matrix**

**Risk Reduction Measure** — **IRRM Evaluation Criteria (USACE Bulletin, 2014)**

**Legend:**
● Factor is well addressed by this measure and/or No Adverse Impact
◒ Factor is marginally addressed by this measure and/or potential concern
○ Factor is not addressed by this measure or not applicable
Priority measure, based on # of factors addressed

| Risk Reduction Measure | Structural (S) or Non-Structural (NS) Measure? | a. Reduce Probability of Inundation | b. No Life Safety Increase | c. No Adverse Impacts to Levees | d. Detection Confidence | e. Notification Confidence | f. Warning Time & Evacuation | g. Reduce Loading | h. Public Trust | i. Problem Understanding | j. Permanent Solution | k. Other project impacts | l. Cost Effectiveness | m. Social / Environmental Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. King County Flood Warning Center and Program | NS | ○ | ● | ● | ○ | ● | ● | ○ | ● | ● | ◒ | ○ | ● | ● |
| 2. King County Flood Patrol and Levee Inspection Program | NS | ○ | ● | ● | ● | ● | ● | ● | ● | ◒ | ◒ | ○ | ● | ● |
| 3. King County Flood Hazard Management Plan | NS | ○ | ● | ● | ○ | ◒ | ○ | ○ | ● | ● | ◒ | ○ | ◒ | ● |
| 4. Public Communication Program: preparedness; education; residual risk | NS | ● | ● | ● | ○ | ● | ● | ○ | ● | ○ | ◒ | ○ | ● | ● |
| 5. Emergency Response (Post Flood Recovery) Program | NS | ○ | ● | ● | ○ | ○ | ○ | ○ | ◒ | ○ | ◒ | ○ | ◒ | ◒ |
| 6. Animal Burrow Response Plan | NS | ◒ | ● | ● | ● | ● | ◒ | ◒ | ◒ | ○ | ○ | ◒ | ● | ● |
| 7. Technical Studies, Assistance and Consultation | NS | ○ | ● | ● | ● | ○ | ● | ○ | ● | ● | ◒ | ○ | ● | ● |
| 8. Flood Hazard Area Regulations | NS | ● | ● | ● | ● | ○ | ○ | ○ | ● | ○ | ◒ | ○ | ● | ◒ |
| 9.Effectiveness Monitoring to Improve Performance | NS | ◒ | ● | ● | ● | ○ | ○ | ○ | ● | ● | ◒ | ○ | ● | ○ |
| 10. Sandbags | S | ◒ | ◒ | ● | ○ | ○ | ○ | ◒ | ○ | ○ | ○ | ◒ | ○ | ◒ |
| 11. Bulk Bags | S | ◒ | ◒ | ◒ | ○ | ○ | ○ | ◒ | ○ | ○ | ○ | ◒ | ◒ | ◒ |
| 12. Earthen Levee Raising (Low Spots) | S | ● | ◒ | ◒ | ○ | ○ | ○ | ● | ○ | ○ | ● | ◒ | ◒ | ◒ |
| 13. Small Capital Projects for Scour & Erosion | S | ● | ◒ | ◒ | ○ | ● | ○ | ● | ● | ○ | ● | ◒ | ● | ◒ |
| 14. Temporary Rock Placement | S | ◒ | ◒ | ◒ | ○ | ○ | ○ | ◒ | ○ | ○ | ○ | ◒ | ◒ | ◒ |

# Chapter 6 Funding and Implementation

This chapter summarizes funding and implementation of the Green River System Wide Improvement Framework Interim Report. SWIF implementation is organized to resolve PL 84-99 deficiencies using a worst-first sequencing approach, keeping in mind funding constraints that limit the pace of capital project implementation. All PL 84-99 deficiencies will be resolved through either a capital project or levee maintenance and operations, or engineering analysis that determines the deficiency to be acceptable. Structural and non-structural interim measures will be implemented as needed, to reduce risks in locations where a capital project or maintenance action is needed, but implementation is delayed.

Section 6.1 provides summary cost tables for three categories of Interim SWIF implementation: capital projects; maintenance and operations; and interim risk reduction measures. Interim SWIF implementation will primarily be funded by King County Flood Control District revenue, as supplemented by other leveraged funding sources. Revenue available to fund Interim SWIF implementation is summarized in section 6.2. This also includes other potential funding sources that may be leveraged to support implementation. Section 6.3 focuses on implementation timing. Section 6.4 summarizes other considerations associated with Interim SWIF implementation specified in the 2011 SWIF policy.

## 6.1 Interim SWIF Cost Summary

Interim SWIF implementation costs are summarized according to three categories: (1) capital projects that resolve slope stability deficiencies, are designed to a 500-year level of protection in specific locations and support future certification (Chapter 3); (2) maintenance and operations programmatic tasks needed to resolve other PL 84-99 deficiencies (Chapter 2 and Chapter 4); and (3) interim risk reduction measures, including both structural and non-structural actions to reduce flood risks (Chapter 5). Categorical cost summary information is further described in Tables 6.1, 6.2 and 6.3. For additional descriptive information, please see referenced chapters.

**Table 6.1** SWIF Capital Project Estimates. All projects summarized in Table 6.1 are needed to resolve PL 84-99 slope deficiencies and achieve slope stability with acceptable Factors of Safety. Each project is further described in Chapter 3 of the SWIF Interim Report.

| CAPITAL PROJECT | DESCRIPTION | COST (ONE TIME)* |
|---|---|---|
| Lower Russell Road<br>RM 17.85 – 19.25 (right bank) | • Setback levee, habitat restoration, and recreational/ park enhancements | $41-43 million |
| Tukwila 205: Segale-Gaco<br>RM 15.55 – 15.88 (left bank) | • Floodwall with toe/scour protection and riparian revegetation | $13.8-16.6 million |
| Tukwila 205: Ratolo<br>RM 14.6 – 14.75 (left bank) | • Floodwall with toe/scour protection and riparian revegetation | $6.3-7.5 million |
| Tukwila 205: Christensen Rd.<br>RM 13.43 – 13.58 (left bank) | • Floodwall with toe/scour protection and riparian revegetation | $7.5-9.0 million |
| Horseshoe Bend: McCoy<br>RM 24.26 – 24.47 (right bank) | • Major modification for City of Kent secondary levee or in-place replacement levee | $0.4-4.7 million |
| Horseshoe Bend: Breda | • In-place replacement levee and partial | $6.9-8.6 million |

| CAPITAL PROJECT | DESCRIPTION | COST (ONE TIME)* |
|---|---|---|
| RM 24.47 – 24.7 (right bank) | setback with toe/scour protection; riparian revegetation (including large shade trees) | |
| Horseshoe Bend: Nursing Home<br>RM 25.4 – 25.65 (right bank) | • Floodwall or in-place replacement levee with toe/ scour protection; riparian revegetation | $8.7-11.7 million |
| **TOTALS** | | **$84.6-101.1 million** |

* Note: Lower Russell costs based on 30% design; all other costs based on planning level cost estimates for design, construction, and acquisition, including contingency.

**Table 6.2** PL 84-99 Levee Maintenance and Operations. This table summarizes the costs associated with the maintenance of PL 84-99 levees, including resolution of PL 84-99 deficiencies, not addressed through capital projects. Deficiency corrective actions are further described in Chapter 2 (Deficiency Action Plan) and Chapter 4 (Vegetation Plan) of the SWIF Interim Report.

| Maintenance & Operations | DESCRIPTION | COST (ANNUAL) | COST (ONE-TIME) |
|---|---|---|---|
| Vegetation | • Brushing & mowing to support inspections (fall, before flood season)<br>• Hazard tree management (public safety and levee integrity)<br>• Establishment and maintenance of vegetation in the vicinity of levees and floodwalls | $460,000 | n/a |
| Encroachments | • Evaluation and correction of encroachments (fences, gates and other private installations) on levees or their inspection zones<br>• Confirmation of access to levee inspection zones | $40,000 | $198,000<br><br>(document levee inspection zone property access authorities) |
| Culverts | • Evaluation and correction of outflows and flood closure devices located in the vicinity of levees<br>• Inspection of each device every 5 years | $80,000 | n/a |
| Animal burrows | • Complete pilot project and prepare response plan<br>• Ongoing inspections and management | $55,000 | $37,000 |
| Assessments, surveys and monitoring | • Site specific assessments by licensed engineers to verify effects of PL 84-99 deficiencies to levee integrity<br>• Ongoing levee system condition monitoring, twice per year | $145,000 | n/a |
| **TOTALS** | | $780,000 | $235,000 |

Note: In addition to levee related costs included here, there are also Green River pump station (Black River, P-17 and Segale pump stations) annual O&M costs (including pump station operators) of approximately $750,000.

**Table 6.3** Interim Risk Reduction Measures (IRRM). Interim flood risk reduction measures are the structural and non-structural activities that reduce flood risks, while capital projects are being completed. In some cases, there may be a delay in levee maintenance, in which case an interim risk reduction measure may be needed. For example, all levee penetrations (pipes, culverts, flap gates) are assessed and if needed corrected through levee maintenance activities. It may be necessary to institute additional monitoring as an interim risk reduction measure, if a specific levee penetration project is delayed. Additional detail is provided in Chapter 5 (Interim Risk Reduction Measures).

| IRRMs | DESCRIPTION | COST (ANNUAL RECURRING) | COST (AS NEEDED OR ONE-TIME IN 6-YEAR PERIOD) |
|---|---|---|---|
| **Structural IRRMs** | | | |
| Sandbags | Provision of sand bag materials in three sites: Tukwila, Kent and Auburn | $8,000 | - |
| Bulk bags | Installation and removal of bulk bags; bags provided by USACE | n/a | Variable ($200,000/mile) |
| Earthen levee raising | Elevation of low spots in the levee system for emergency floodwater containment purposes (currently identified for Tukwila and Kent; Need further evaluation for Galli's/Dykstra levees in Auburn) | n/a | $60-100/linear foot + acquisition costs, if necessary |
| Small capital for scour/erosion | | n/a | $2500-3500/linear foot for pilings and wood/rock buttress; $650/foot for willow staking |
| Temporary rock placement | | n/a | $1000-2000/linear foot |
| **Non-structural IRRMS** | | | |
| Flood warning center | Countywide program cost | $230,000 | n/a |
| Flood patrol and inspection | Countywide program cost | $175,000 | n/a |
| Flood Plan | Cyclical (plan is updated every 5 years); Countywide flood plan costs | n/a | $80,000 |
| Communication | Countywide program cost | $80,000 | n/a |
| Emergency response, post flood recovery | Countywide program cost | n/a | Variable, depends upon # of flood events ($58,000/flood event) |
| Technical studies and assistance | Countywide program cost | $30,000 | $12,000 (prepare maps and report of PL 84-99 levee system low points) |
| **TOTALS** | | $523,000 | N/A |

## 6.2 Revenue

Revenue to support implementation of the Interim SWIF includes King County Flood Control District managed funds and a variety of other potential grant sources. The King County Flood Control District's anticipated revenue for 2016 is $56,000,000, which funds projects and programs countywide. The 6-year capital budget for the Green River from 2016-2021, including 2015 carryover, is approximately $68 million. A separate maintenance budget will fund O&M costs, as shown in Table 6.2.

Other potential revenue sources that may be leveraged to support implementation of the Interim SWIF include:

- U.S. Army Corps of Engineers Continuing Authorities Program (section 205 funding)
- USACE (Section 1135 of Water Resources Development Act of 1986) – Project modifications to improve the environment
- U.S. Army Corps of Engineers Ecosystem Restoration Program
- U.S. Army Corps General Investigation
- National Estuary Program
- Floodplains by Design
- Salmon Recovery Funding Board
- WA State Legislature Direct Appropriation
- King County Mitigation Reserves Program
- King County Conservation Futures Tax
- Local cities

## 6.3 Implementation Timing

Correcting PL 84-99 deficiencies is a cornerstone of the Flood Control District's flood risk reduction program within the Lower Green River. Slope stability deficiencies will be primarily resolved through SWIF capital projects. In locations where large capital projects are planned (e.g., Lower Russell), all other deficiencies in the capital project area will be corrected. Most of the remaining deficiencies will be corrected through levee maintenance and operations actions, or small capital projects. For example, it may be necessary for cities or private landowners to replace culverts or install backwater control. Table 6.4 highlights the implementation timeframe for capital projects and maintenance and operations tasks needed to resolve other deficiencies. Funding availability will govern the pace of implementation of capital projects needed to resolve slope stability deficiencies. Proposed capital project sequencing is guided by worst-first criteria and concepts of risk management.

**Table 6.4** SWIF Implementation Timing

| SWIF activity | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Russell CIP | | | | | | | | | | | | |
| HSB: Breda CIP | | | | | | | | | | | | |
| Tuk205: Segale-Gaco CIP | | | | | | | | | | | | |
| HSB: Nursing Home CIP | | | | | | | | | | | | |
| Tuk205: Ratolo CIP | | | | | | | | | | | | |
| HSB: McCoy CIP | | | | | | | | | | | | |
| Tuk205: Christensen CIP | | | | | | | | | | | | |
| Levee Maint &Operations* | | | | | | | | | | | | |
| SWIF Progress Reports | | | | | | | | | | | | |

6-Year CIP that is partially funded and preliminary design could be initiated
6-Year CIP design + construction to correct PL 84-99 slope deficiencies
CIP, out years, to correct PL 84-99 slope stability deficiencies
PL 84-99 levee maintenance and operations*
SWIF implementation progress reports, submitted to USACE

*Levee maintenance and operations includes: vegetation management; animal burrow management; monitoring of culverts, encroachments and other potential risks to levee stability; evaluation and correction (if needed) of pipes, culverts, flapgates, fences and encroachments; site surveys, site assessments and other technical studies. See Chapter 2 for additional detail.

## 6.4 Implementation Considerations

The 2011 policy governing SWIF preparation requires that local sponsors summarize known agreements that have the potential to influence implementation of the SWIF. A list of known agreements associated with the current PL 84-99 system of levees in the Lower Green includes:

- Lower Green River Flood Damage Reduction Project Operations and Maintenance Manual (1993) authorizing Tukwila as the local sponsor of the federal Tukwila 205 Project
- Interlocal agreement (Resolution Gr.194-1) between city of Tukwila and the Green River Flood Control District establishing maintenance responsibility for the Tukwila 205 Project
- Horseshoe Bend Flood Reduction Project agreement between United States of America and Green River Flood Control District; 1996
- Agreement for Levee Construction, Operation and Maintenance Briscoe-Desimone Levee between King County Flood Control District and Kent; 2013
- Cooperation Agreement Between the United States of America and The King County Flood Control District For Rehabilitation of a Non-Federal Flood Control Work Desimone-Briscoe School Levee, Job No. Grn-01-14; 2015
- Agreement for levee Construction, Operation and Maintenance for the Boeing Levee and Hawley Road Levee. Between King County Flood Control District and Kent; 2011

- Revised Agreement for Levee Construction, Operation and Maintenance-Russell Road Upper Levee-North Reach and South Reach, between King County Flood Control District and Kent; 2015

The 2011 SWIF policy also requires that local sponsors inform FEMA regarding accredited levee systems that contain unacceptable inspection items, and, how these items will be addressed through SWIF implementation. King County Flood Control District will maintain ongoing communication with FEMA during SWIF implementation, to inform future FEMA mapping and accreditation projects. The Tukwila 205 levee is the only system in the Lower Green that was formerly certified through the U.S. Army Corps of Engineers. Tukwila is currently leading a levee certification process for the Tukwila 205 levee. Certification studies are anticipated to be completed in 2016, at which point unacceptable inspection items will be communicated to FEMA. SWIF implementation, as it relates to Tukwila 205, will be informed by these forthcoming technical studies and recommendations.

The King County Flood Control District proposes to submit bi-annual SWIF implementation progress reports to the U.S. Army Corps of Engineers, to document progress in resolving deficiencies and implementing the Interim SWIF through capital projects, maintenance and operations, and Interim Risk Reduction Measures. Progress reports will also contain a summary of lessons learned from the previous two years of SWIF implementation, with accompanying recommendations on how to improve the efficiency and effectiveness of resolving outstanding PL 84-99 deficiencies and achieve flood risk reduction outcomes.

Green River System Wide Improvement Framework Interim Report

# APPENDICES

**Appendix A: Aquatic, Floodplain and Riparian Habitat Technical Memorandum**

**Appendix B: Geomorphology Technical Memorandum**

**Appendix C: Geotechnical Technical Memorandum**

**Appendix D: Hydraulics Technical Memorandum**

**Appendix E: Economics Technical Memorandum**

**Appendix F: Howard Hansom Dam Preliminary Capacity Evaluation**

**Appendix G: Lower Green River Solar Radiation Priority Areas Maps**

King County

# GREEN RIVER, KING COUNTY, WASHINGTON
# SYSTEM-WIDE IMPROVEMENT FRAMEWORK (SWIF)

Photo Credit: King County

## ATTACHMENT A:
# AQUATIC, FLOODPLAIN, AND RIPARIAN HABITAT TECHNICAL MEMORANDUM

## FINAL

## MAY 2014

# GREEN RIVER SWIF

# CURRENT CONDITIONS REPORT

# AQUATIC, FLOODPLAIN AND RIPARIAN HABITAT TECHNICAL MEMORANDUM

## FINAL

Prepared by King County Department of Natural Resources and Parks

and

## MAY 2014

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# 1. INTRODUCTION

The Green River System Wide Improvement Framework (SWIF) is a collection of technical planning, engineering, and economic analyses being conducted by the King County Department of Natural Resources and Parks (King County), the King County Flood Control District (District) and cooperating stakeholders. The studies being conducted as part of the SWIF are focused on addressing issues such as flood risk, levels of protection and vegetation management. The SWIF will produce a prioritized list of potential projects in the Green River watershed intended to minimize risks due to flooding while also improving the quality of the habitat and water temperatures in the Lower Green River to sustain Chinook salmon and other species. Because federal Endangered Species Act (ESA)-listed salmon and trout are present in the Green River and King County, the District and other local jurisdictions are responsible for implementing salmon recovery actions, complying with federal requirements such as the Clean Water Act and FEMA standards, protecting tribal treaty rights, and mitigating impacts from flood control practices. To fully inform this process requires information on the historic and current conditions of the aquatic and floodplain habitats and fish resources in the Green River. This technical report synthesizes existing information on the Green River watershed, with emphasis on the Lower Green River, defined as the river from river mile (RM) 11 through RM 32, where flood-related risks are greatest.

This technical report is based on a review of currently available literature, maps, GIS data files, and 2013 LiDAR data. The majority of document sources were produced by the Water Resources Inventory Area 9 Technical and Steering Committees, the King County Department of Natural Resources and Parks, Anchor QEA, and R2 Resource Consultants. Water quality information was based primarily on the Green River temperature total maximum daily load (TMDL) (Coffin et al. 2011), and WRIA 9 Strategic Assessment (King County and WRIA 9 2005).

## 1.1. STUDY AREA

The Green River arises in the central Cascade Range, flows northwesterly for over 93 miles, and enters Puget Sound in Elliott Bay. Where the Black River joins the Green River the name changes to the Duwamish River. The current drainage area for the Green River basin is 482 square miles (WRIA 9 Steering Committee 2005). The Green River basin has been heavily modified over time and its drainage area has been substantially reduced as a result of the diversion of the White River and the Cedar/Black Rivers out of the basin. The alluvial fan of the White River south of Auburn is a low divide between the Green and Puyallup River basins. In 1906, a major flood created a log jam near this location and temporarily diverted the White River into the Puyallup River; in 1911 the White River was permanently diverted to reduce flooding near Auburn. Between 1912 and 1916, the Cedar River was diverted into the Lake Washington system to provide water to operate the newly constructed Hiram Chittenden Locks, eliminating most flow from the Black River. The Tacoma Headworks Diversion Dam (Tacoma Diversion Dam) was completed in 1913 and Howard Hanson Dam was constructed in 1962.

The Green River SWIF project area includes Howard Hanson Dam, located at RM 64.5 downstream to the end of leveed reaches at approximately RM 5.5. The focal geographic area for the Green River SWIF is the Lower Green River (Figure 1-1). Within the Lower Green River, there are approximately 18 miles of levees, of which five systems are currently enrolled in the U.S. Army Corps of Engineers' Levee

Rehabilitation and Inspection Program, authorized by Public Law 84-99 (PL84-99) and are a priority project focus. A brief discussion of a portion of the Middle Green River up to Flaming Geyser Park (RM 32-45) and the upper portion of the Duwamish River (RM 5.5 to 11) that includes some levee segments, are included as context for the Lower Green River (Figure 1-2). Stream flows in the Lower Green River have been highly modified, most dramatically by the White River and Black/Cedar River diversions described above, and also by the construction of the dams in the upstream reaches of the Green River. The White River diversion is estimated to have reduced summer flows in the Green River by about 50% (Kerwin and Nelson 2000). Of the 1,900 miles of rivers and streams historically accessible to anadromous fish in the watershed (prior to diversions), only 125 miles were accessible by 1985 (Kerwin and Nelson 2000). Remaining tributaries to the Lower Green River that are known to provide habitat for anadromous fish include the Black River/Springbrook Creek, Mill Creek, and Mullen Slough (WDFW 2014; King County and WRIA 9 2005).

The Lower Green River study area includes the incorporated cities of Tukwila, Kent, and Auburn, as well as the Agricultural Production District (APD), which is unincorporated King County. Current land-use in the study are consists of about 50% residential, 27% commercial and industrial, and 23% agricultural and other open or mixed use categories (King County and WRIA 9 2005). Much of the Lower Green River is currently bordered by levees along one or both banks (King County and WRIA 9 2005); levees were originally constructed to support agriculture (Figure 1-3).

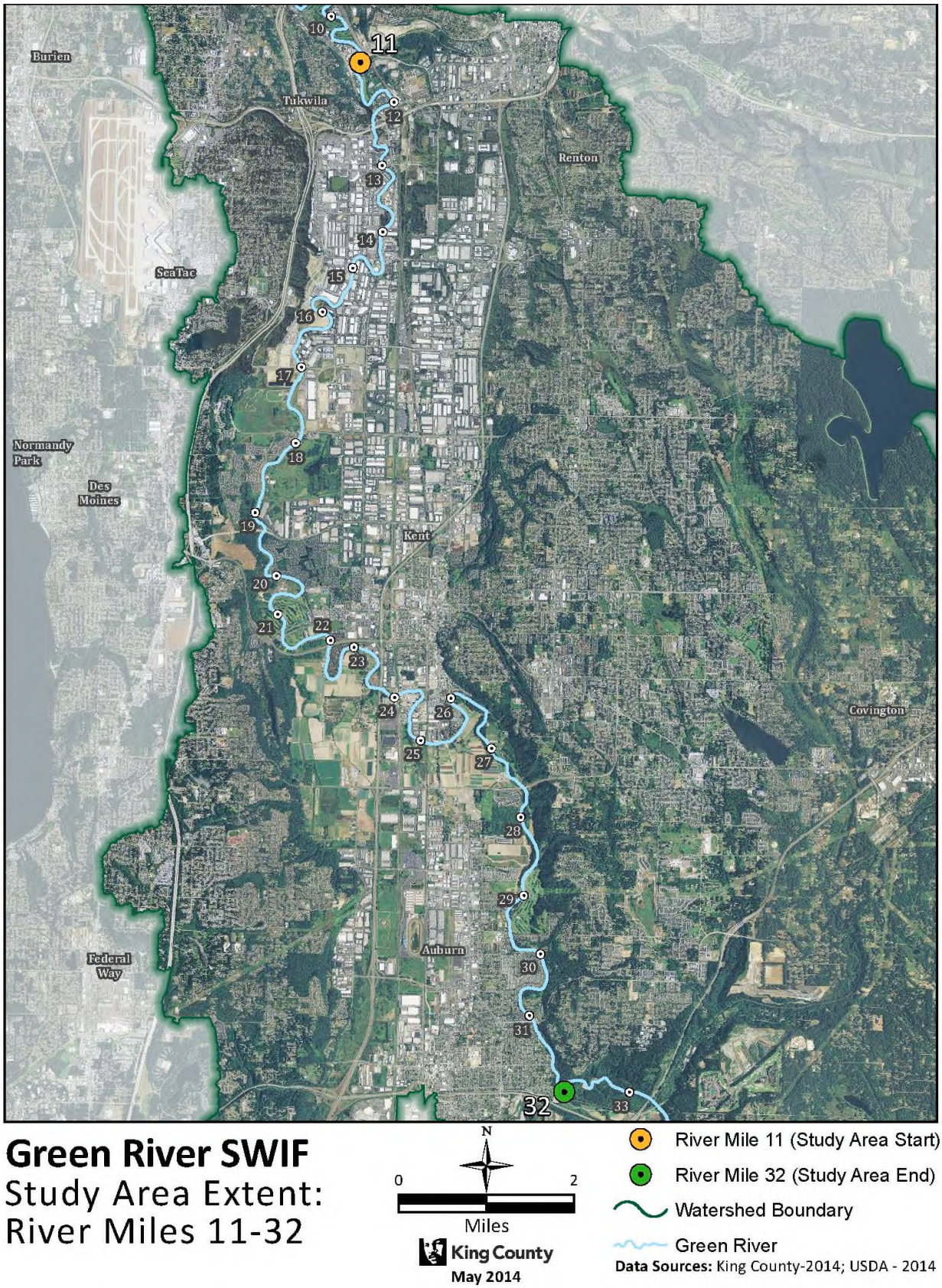



**Figure 1-1. Primary Habitat Study Area, RM 11-32.**

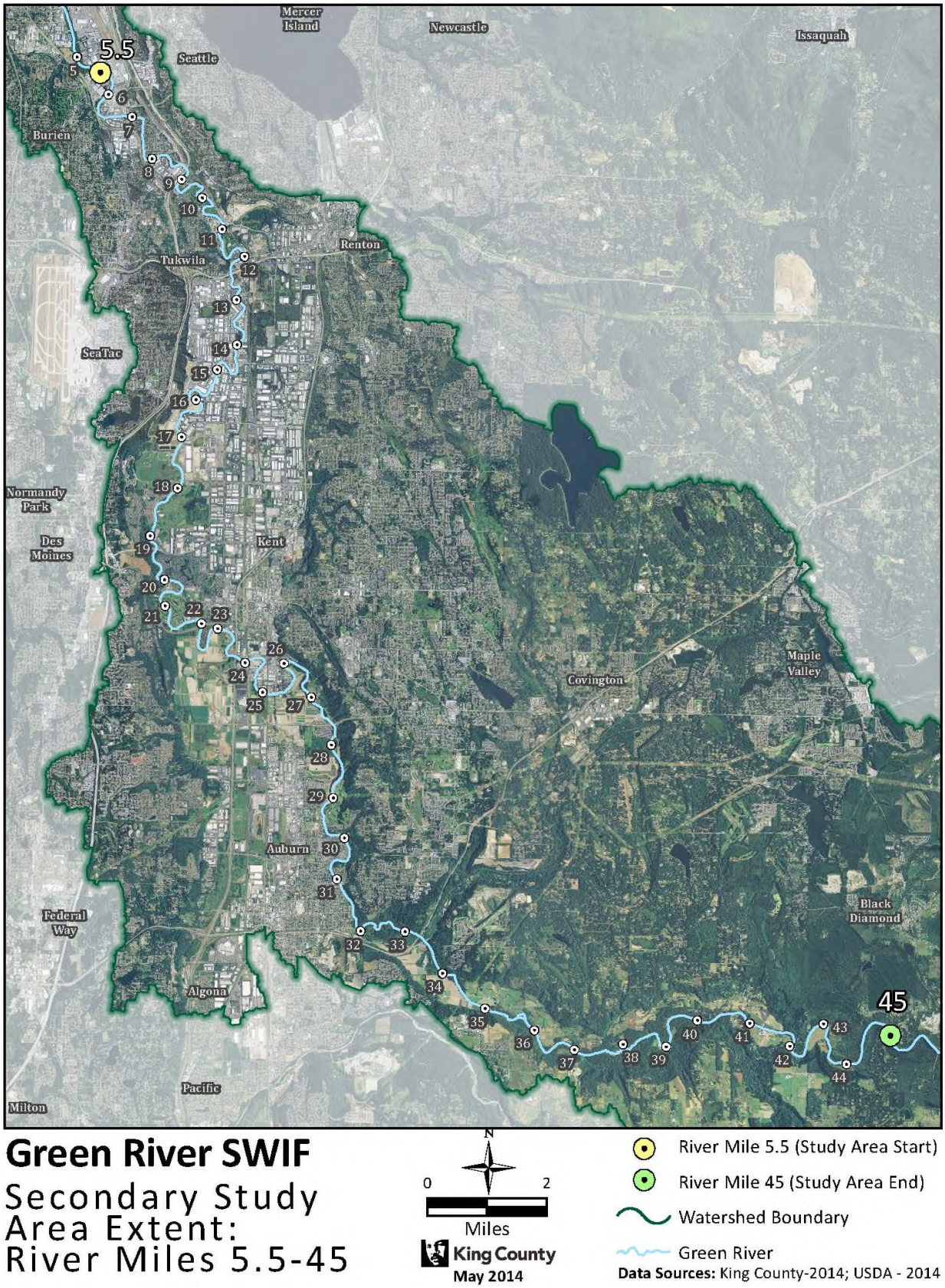
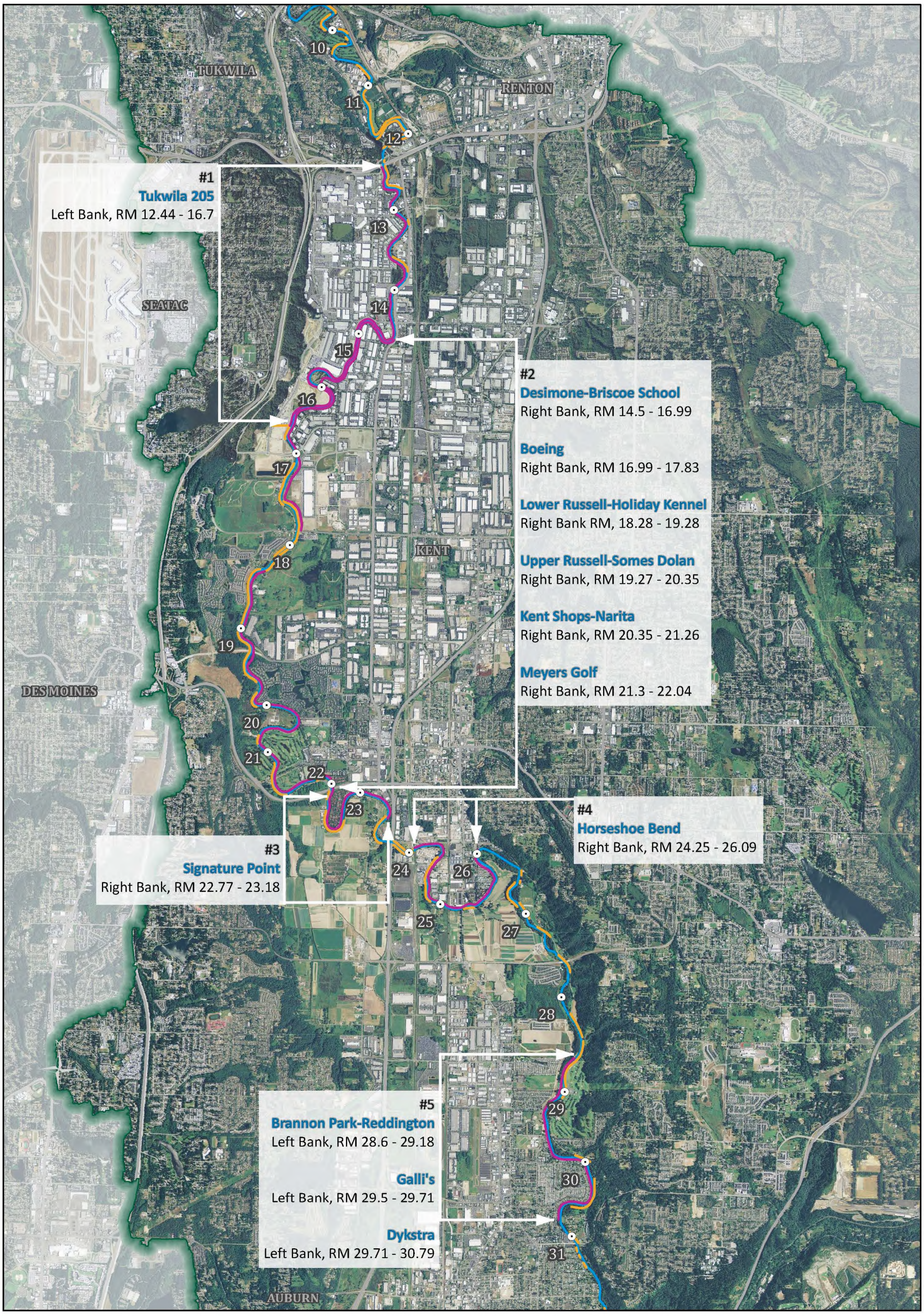



**Figure 1-2. Expanded Study Area, RM 5.5 to 44.**




**Green River SWIF**

Green River
Flood Protection
Infrastructure

N

0 2
Miles

King County
May 2014

USACE-SWIF Levee Systems
Levees and Revetments (Non-SWIF)
Green River
Watershed Boundary
River Miles

**Data Sources:** King County-2014, USDA - 2014

**Figure 1-3. Levee Systems**

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# 2. Historic Habitat Conditions and Changes Over Time

Diversion of the Black/Cedar River and White River from the Green River Basin has significantly reduced watershed area, resulting in huge effects on aquatic and floodplain habitats. Historically, the Lower Green River was highly influenced by the White River, which contributed flow, wood, and sediment, as well as cold glacial-derived water, to the Lower Green River (Kerwin and Nelson 2000). Each of these factors was a crucial component in the creation and maintenance of the complex mosaic of main channel, side-channels, gravel bars, pools, and complex instream and riparian cover that characterized historic riverine and floodplain habitats on the Lower Green River.

The following sections highlight the key types of vegetation and habitats present in distinct historic time periods.

## 2.1. Pre-1880s: Native American civilization

Following the Osceola Mudflow approximately 5,700 years ago and prior to 1851, the Green River valley was inhabited by Native Americans. The inhabitants of the current-day Lower Green River Valley included many villages collectively referred to by settlers and government officials as the Stkamish, the Smulkamish, and the Skopamish, the descendants of which are now members of the Muckleshoot Indian Tribe (White River Journal 2001). Cedar trees were used for building houses and canoes, and cedar bark was used to create baskets, rope, and clothing (Center for the Study of the Pacific Northwest 2014). Small clearings were likely created and maintained using fire (Collins and Sheikh 2005). Native Americans traveled by water or trail. Early reports described the vegetation in this area as particularly dense, and overhanging the river (Bagley 1929).

The Lower Green River banks were higher in elevation than the surrounding floodplain. Sediments carried by the river created natural levees along the banks. Frequent overbank flooding inundated the floodplain. An assessment of historical habitat conditions in the mid-1800's suggests that the Lower Green River contained an extensive network of wetlands and floodplain channels, including significant wetland habitat in the vicinity of Mill Creek and a "complicated mosaic" of wetland and forested floodplain habitat on the eastern bank downstream of present-day Kent (Collins and Sheikh 2005). Extensive floodplain habitat located along the right bank of the Lower Green River, below current RM 22, collected overbank floodwaters and drained to the north through the Springbrook Creek drainage into the Black River, where the floodplain waters rejoined the Lower Green River. Collins and Sheikh (2005) provide an excerpt from an 1898 Army engineer report which specifically described the Lower Green River (then referred to as the Lower White River) and its vegetation as follows:

*"The banks of the White River are covered with a dense growth of alder, willow, and vine-maple brush, which overhangs the low-water line…" (Ober 1898)*

The overall extent of slow-water edge habitat that is heavily used by juvenile salmonids was dominated by the network of floodplain channels below RM 22, in contrast to RM 22-32 where edge habitat was mostly associated with mainstem river channels (Collins and Sheikh 2005). In terms of overall area, the wetland habitat far surpassed the area of channel habitat due to the large extent of floodplain. Overall,

the Lower Green River valley was estimated to contain nearly 740 acres of mainstem channel habitat and nearly 3,800 acres of wetland habitat, including 227 acres of tributary habitat, as well as 84 additional acres of floodplain pond habitat (Figure 2-1 and Table 1).

The riparian community within the floodplain habitat was dominated by hardwood forests, with large diameter trees such as cottonwood and big leaf maple common along stream margins (Collins and Sheikh 2005). These species contributed large wood into the mainstem and secondary (floodplain) channels.

At approximately RM 18, a native village called Stook meant "a big jam of logs" (Hilbert et al. 2001). The quantity of wood likely created complex in-stream habitats including pools and gravel bars and multiple channels.

**Table 1. Comparison of Historic to Current Floodplain Land Cover Types from RM 11 to 32.**

| Cover Type | 1865 | | 2011 | |
|---|---|---|---|---|
| | Acres | Percent Land Cover | Acres | Percent Land Cover |
| **Water (Ponds, lakes)** | 84 | <1% | 22 | <1% |
| **Uplands** | 39 | <1% | -- | -- |
| **Bare Earth** | -- | --- | 204 | 1% |
| **Herbaceous vegetation (historical prairies, grassy areas)** | 188 | 1% | 253 | 1% |
| **Mainstem River Channel** | 734 | 4% | 428 | 2% |
| **Forest** | 14,566 | 75% | 1,517 | 8% |
| **Wetlands** | 3,798 | 20% | 2,579 | 13% |
| **Developed** | N/A | -- | 14,408 | 74% |
| ***Total Area*** | ***19,409*** | | ***19,409*** | |

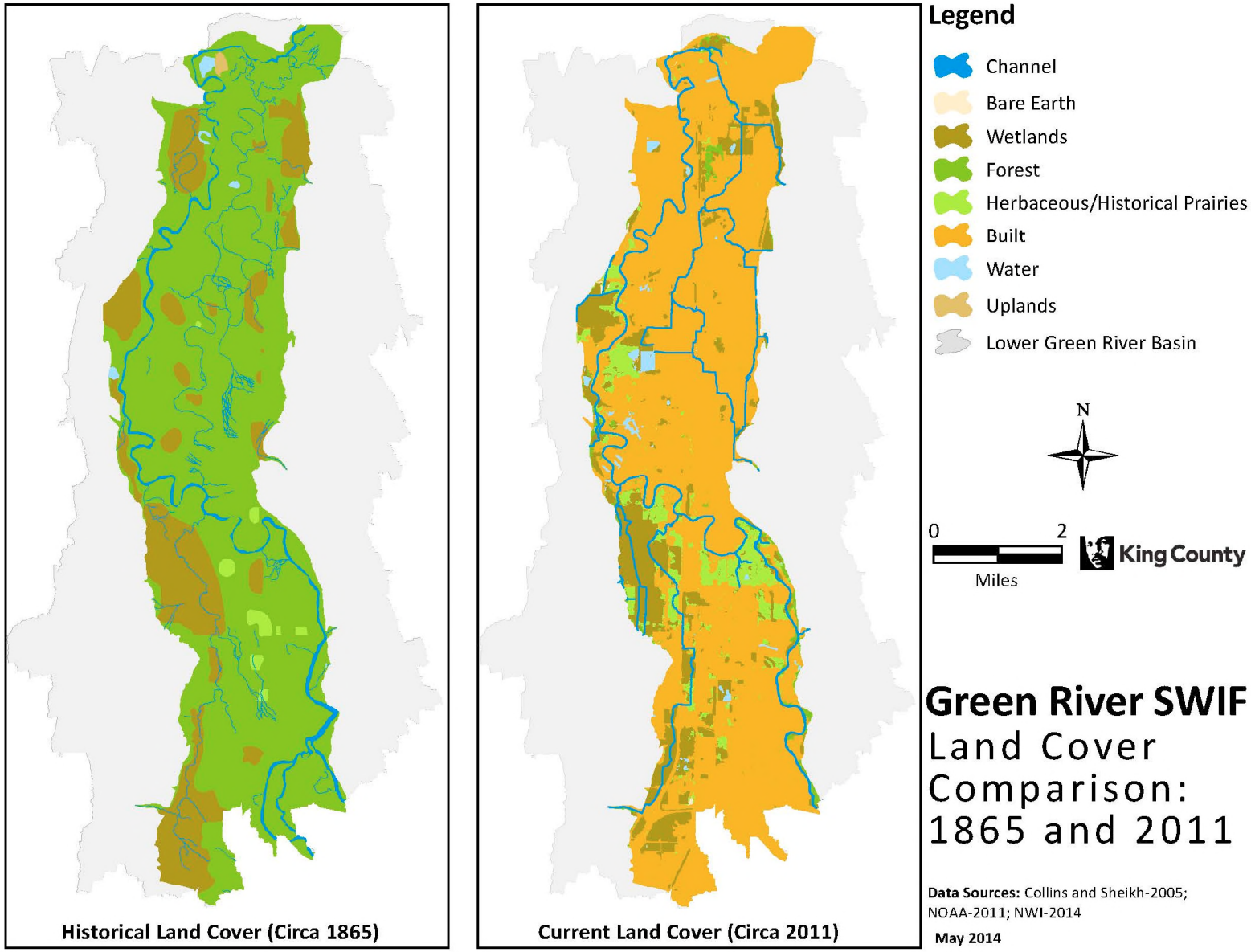


**Figure 2-1. Current Land Cover and Channels in the Lower Green River as Compared to Historic Conditions.**

## 2.2. 1880-1950s: Agriculture and Channelization

Widespread logging to facilitate agriculture throughout the Lower Green River valley began in the 1880s and continued until approximately 1910 (WRIA 9 Steering Committee 2005), and the area between Auburn and Tukwila was extensively farmed (Figure 2-2). Railroads were also constructed during this time; the railroads allowed for rapid travel between Tacoma and Seattle. Diversion of the Cedar, Black, and White Rivers away from the Green River permanently reduced flows in the modern Green and Duwamish Rivers (Chittenden et al. 1907; Hanson 1957; Konrad et al. 2011). Some private levee construction to reduce flooding began in 1919 (WRIA 9 Steering Committee 2005).

Clearing of vegetation was noted to cause channel bank erosion and undermining in the same Ober (1898) report that had noted the dense growth of willows and other shrubs:

*"This brush affords complete protection against the washing and undermining effects of the current. In a majority of cases where the brush has been removed the river has begun to eat into the bank. (Ober 1898).*

A committee appointed to investigate flooding issues in the Duwamish, White, and Puyallup River systems, headed by US Army Corps of Engineers Major Hiram Chittenden, reported:

*"The watershed is everywhere heavily timbered and the trees along the banks are constantly being undermined and dropped into the channel." (Chittenden et al. 1907)*

This latter report is likely more specific to the White and Middle Green Rivers, where channel migration reduced the extent of forest cover and recruited wood to the river (Konrad et al. 2011), rather than the Lower Green River where extensive clearing was occurring. The post-diversion Lower Green River had a relatively narrow meander belt (Collins and Sheikh 2005).

**Figure 2-2. Green River Valley, in the vicinity of Tukwila and Kent, WA in 1936.**

The development of flood control levees following the 1906 flood progressed as the human population and urban development continued to expand into the late 1900's. The levee system, as well as the diversion of the White and Black/Cedar rivers, dramatically reduced the capability of the Lower Green River mainstem channel to access its floodplain and wetland habitat. The diversion of the White River and construction of dams in the upper Green River also resulted in significant reductions in the recruitment of sediment (including spawning gravels) and woody debris into the Lower Green River, with resulting declines in instream habitat diversity.

## 2.3. 1957-1990: Flood Control and Industrialization

Completion of Howard Hanson Dam in 1962 further reduced peak flows and interrupted the transport of sediment and wood through the system. Levees and revetments were constructed in the 1960s by creating an earthen prism on the river bank and then lining the riverward face with rock. The Green River flood control system (Howard Hanson Dam in addition to the levee system) allowed for the industrialization of the Green River valley. Annexations continued and agricultural lands converted rapidly to industrial and residential land uses. The Green River Valley started to become a major industrial center.

The Green River Flood Control Zone District was formed in 1960 by Resolution 31192 of the King County Board of Commissioners with concurrence from the affected lower Green River Valley cities (Green River Basin Program 1993). In 1978, King County and Valley cities signed an inter-local agreement to form the Green River Basin Program (Green River Basin Program 1993). This Program supported a more comprehensive and programmatic inter-jurisdictional flood control and drainage program for the Lower Green River basin. Levee repair and maintenance was funded by the River Improvement Fund, a countywide property tax levy. Maintenance activities focused on mowing invasive vegetation to facilitate levee inspections and repairing damages with additional rock (Ken Krank, personal communication, 2013).

## 2.4. 1990-2006: Evolving Levee Repairs

In 1990, thirty years after its formation, the Green River Flood Control Zone District was activated. The purpose of the District was to provide a funding base for operation and maintenance of levees, revetments, and pump stations on the Green River and to fund administration of the Green River Basin Program. The District's work program was funded by a property tax levy. The District provided significantly enhanced financing capability for floodplain management and river maintenance plans and projects over what was available with the River Improvement Fund (Dave Clark, personal communication, 12 December 2013). Around this time, several King County levees were enrolled in the federal PL84-99 program, in order to cost-share levee repairs in the event of flood damage (Dave Clark, personal communication, 12 December 2013). As previously noted, the Green River Valley was extensively developed by this time (Figure 2-3).

**Figure 2-3. Green River in the vicinity of Tukwila and Kent, 1998.**

By the early 1990s, engineers, scientists and natural resource managers began to consider other options than traditional bank armoring approaches. The social, political, and legal environments for riverine projects were shifting as the region moved toward the Endangered Species Act (ESA) listing of Puget Sound Chinook and bull trout in 1999. River engineers began to consider the effects of bank armoring on riverine ecosystems including aquatic and riparian habitats, and downstream flood conditions. High water temperature and low dissolved oxygen levels were also identified in the Green River, which led to the listing of the Green River as an impaired waterbody on the Clean Water Act (CWA) 303(d) list.

Tracking a paradigm shift in river management approaches, new bank stabilization approaches emerged (Johnson and Stypula 1992). Rather than relying solely upon rock armoring, engineers began to employ a combination of rock, wood, soil, and plants to create a complex matrix of bank materials designed to mimic natural processes and strengthen the bank (Figure 2-4). As the vegetation becomes established, the bank becomes naturally stronger and more resistant to erosion, reducing the need for maintenance (Johnson and Stypula 1992). The use of large wood and vegetation was intended to improve fish and wildlife habitat and provide shade. This approach offered a more environmentally sensitive, low-maintenance, and cost-effective alternative to traditional bank stabilization designs in areas where large-scale levee setbacks were not feasible. These techniques were also approved by permit agencies on a case-by-case basis as on-site mitigation for the bank repair work itself.

**Figure 2-4. Schematic of a bioengineered bank with wood and rock at toe and vegetated geogrids (from Johnson and Stypula 1992).**

Between 1990 and 2006, King County constructed several bioengineered bank stabilization projects using these techniques (Appendix B). The majority included geogrids with willow stakes, shrub plantings, and large wood installed in the toe (Figure 2-5). Fewer repairs included tree plantings. The Corps also constructed four bank repairs during this time that included geogrids, shrubs, and large wood (Appendix B).

**Figure 2-5. Photos of the Narita Levee repair, completed in 2003, photos from 2006. (a) Large wood at toe; (b) plantings.**

Levee maintenance during this timeframe focused on maintaining flood patrol access along levee crests and removing invasive plants from bioengineered bank repair project sites; there was not sufficient funding to mow the entire levee system and still have money left for repairs (D. Clark, pers. comm. 2013; A. Levesque, pers. comm. 2013). Beginning around 2000, King County began mowing about 25 feet down the slope at the federal PL84-99 levees (such as at Tukwila 205 and Horseshoe Bend). Willows were occasionally thinned (no more than one-third) to provide willow stakes for new bioengineered bank repair projects and to thin vegetation to promote growth of coniferous underplantings (J. Koon,

pers. comm. 2013). King County did not actively remove trees (S. Bleifuhs, pers. comm. 2013; D. Clark, pers. comm. 2013).

## 2.5. 2006-Present: Recent Levee Management

Following upon broader events in the country (Hurricane Katrina), the Corps began to take a more serious review of the condition of levees and other flood risk management infrastructure and the potential for vegetation to reduce the reliability of the infrastructure. In 2006, King County removed 32 trees from one federal PL84-99 levee system (Tukwila 205) upon request from the Corps and City of Tukwila. In 2008, the Corps identified over 400 trees that should be removed from levees in the Green and Snoqualmie Basins. King County subsequently removed five levees from the PL84-99 program, which brought the proposed number of trees to be removed down to approximately 100. A separate request identified over 60 trees for removal at the Horseshoe Bend levee. King County decided to act on the vegetation removal request and began the permitting process in fall 2008.

A major flood occurred in January 2009. During this event Howard Hanson Dam experienced a record flood pool of 1188.8 feet on 9 January (top of dam elevation 1228.0 feet). After the record flood pool, conditions were observed that indicated seepage and internal erosion may have initiated within the right abutment, raising concerns that the risk of dam failure may have significantly increased for future flood storage pools. These concerns resulted in flood pool restriction at the dam and heightened flood awareness in the valley. King County, the Corps, and the valley cities began hydraulic studies to predict the impact a dam failure would have on the valley, and the Corps embarked on a two-year dam repair effort. Temporary flood barriers were placed on top of the levees to increase the level of flood containment. The Corps conducted additional levee inspections and requested additional tree removal.

In February 2009, the Corps requested removal of additional trees at Horseshoe Bend. King County, Kent, and the Corps met on the levee and discussed the benefits and risks associated with individual trees; approximately 40 trees were removed from the list. In September 2009, King County responded to requests from the Corps and the City of Tukwila by agreeing to remove 360 more trees from the Lower Green. In fall 2009, King County cut 461 trees from the Tukwila 205, Desimone, Briscoe, Holiday Kennel, Russell Upper, Narita, Signature Pointe, Horseshoe Bend, and Dykstra levees (Figure 2-6). In 2010, King County responded to a request from the Corps and the City of Tukwila to thin approximately 1400 linear feet of willows to 4-foot diameter clumps on 30-foot centers (Figure 2-7).

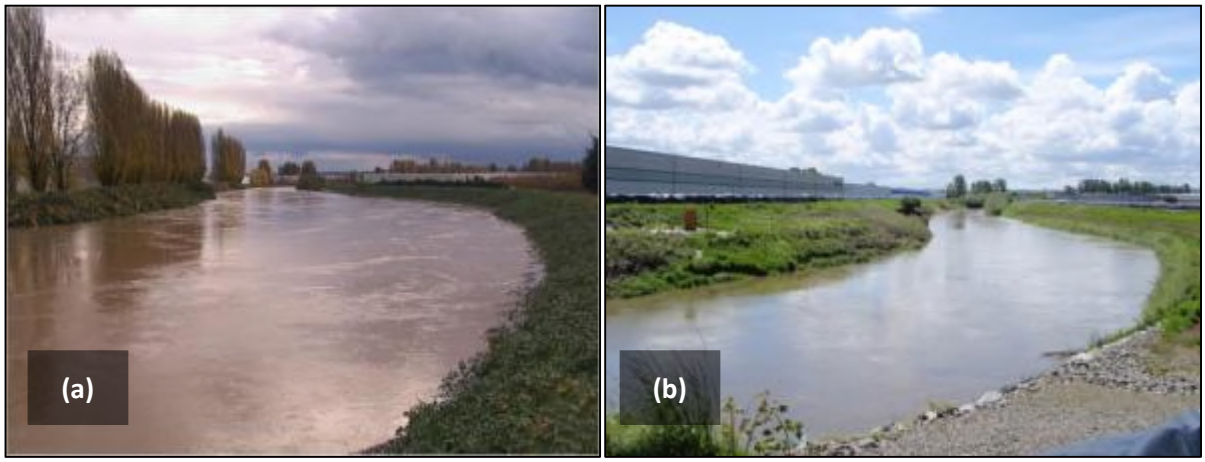


**Figure 2-6. Before and after photos from the Desimone PL84-99 levee (RM 15). (a) 2006; (b) following tree cutting in 2009.**

**Figure 2-7. Before and after photos from the Tukwila 205 PL94-99 levee (RM 14.2). (a) 2010 before thinning; (b) 2010 after thinning.**

The Washington State Hydraulic Project Approvals for the two tree cutting actions (2006 and 2009) required mitigation. One piece of large wood was to be placed in the water for every tree removed from the waterward side of the levee, and four trees were to be planted for every tree removed. The three local jurisdictions affected (Tukwila, Kent, and Auburn) required that the mitigation occur within city limits. The 2006 tree cutting on the Tukwila 205 levee was mitigated with a planting and wood installation project at the Foster Golf Course in Tukwila. However, the 2009 tree cutting has not been fully mitigated. As of 2013, King County still needs to plant over 1,000 trees at a mitigation site in Kent and install 129 pieces of wood at three discrete project sites.

Since 2006, King County and the Corps also completed several repair projects and one large-scale levee setback project at the Reddington site (Appendix B). Trees and shrubs were planted at 18 sites, and wood was installed at 14 sites. For the PL84-99 repairs constructed in 2008 and 2009, the Corps determined that trees could be planted on a mid-slope bench and that willows could be installed in the toe and lower slope (Figure 2-8). The upper slopes were only planted with grass. Routine maintenance also shifted during this time-frame. The Corps requested that King County mow the levees more extensively, including the back slopes.

**Figure 2-8. Kent Shops-Narita Levee (RM 20.35-21.26), repair constructed in 2008 by the Corps.**

## 2.6. CONCLUSION

The dense native vegetation originally present in the Lower Green River valley has been extensively modified over time, beginning with European settlement, and continuing with agriculture, industrialization, and construction of flood control facilities. Today, the river is characterized by some natural banks with a mix of native and invasive vegetation, rock-armored banks constructed mostly before 1990, and bioengineered repair sites that have vegetation incorporated as a bank stabilization design element.

Levee vegetation management practices along the Lower Green River have changed dramatically over time from mowing of primarily invasive vegetation on armored banks, to a more hands-off approach with incorporation of native vegetation into bank repairs, to selective tree cutting, willow thinning, and more extensive mowing in response to PL84-99 policy and maintenance requirements. King County declined to remove native trees and willows from the levees for several years, but since 2006, has removed several hundred trees and over 1,000 linear feet of willows. Regular mowing, in addition to rock armoring, has likely precluded establishment and growth of native vegetation on the sites that have not been repaired using bioengineering practices.

Approximately 20 levee projects were constructed and planted in the Lower Green River within the past seven years. Tree planting was included as a state permit requirement for most of these projects (some federal projects also required Endangered Species Act Section 7 consultation), and permits specify survival and percent cover performance standards. Though the majority of the vegetation planted more recently has not yet exceeded Corps standards, a key objective of the SWIF process will be guidance on how to manage vegetation while meeting permit requirements, protecting tribal treaty rights, protecting ESA-listed species, and achieving levee safety and reliability along with other multiple objectives for river management.

# 3. Salmon Populations in the Green River Basin

The many changes to the Green River basin from the multitude of human actions over time have affected salmon populations in the basin and contributed to the overall listings of Puget Sound populations of Chinook salmon and steelhead trout as threatened species under the ESA. It is important to understand the status of these species when considering an overall framework for future flood risk management and habitat improvements.

There is little reliable historical information on the abundance and distribution of anadromous and resident salmonid species in the Green River basin. Historically, spring-run and summer/fall-run Chinook, coho, pink, and chum salmon, winter and summer steelhead, bull trout and cutthroat trout have been reported in the Green River basin, and sockeye salmon were also likely present in low numbers. However, many of the fish entering the Duwamish River migrated into the Cedar or White Rivers, which are no longer connected to the Green River. Construction of the Tacoma Headworks Diversion Dam and Howard Hanson Dam effectively cut-off access to the upper Green River basin to all anadromous fish (Kerwin and Nelson 2000).

The following sections describe the historical and current populations of each major salmon species.

## 3.1. Chinook Salmon

Prior to development, both spring-run and summer/fall- run Chinook salmon spawned and reared in the Duwamish/Green River basin (King County and WRIA 9 2005). Spring Chinook (also referred to as stream-type) adults migrated to the upper Green River basin and parts of the White River, holding for several weeks or months prior to spawning (King County and WRIA 9 2005). However, re-routing of the White River away from the Duwamish Basin as well as the Tacoma Diversion eliminated access to much of the headwater habitat typically used by spring Chinook. In contrast to spring Chinook, spawning by summer/fall run Chinook was distributed throughout the watershed. While rerouting of the Cedar and White Rivers reduced the overall habitat accessible to fall Chinook, enough habitat remained in the Green River to maintain the population of fall Chinook.

Using Puget Sound commercial canning data from 1908 and making some assumptions on catch rates and basin sizes, a maximum historic annual run size of 37,700 Chinook is estimated for the Duwamish/ Green watershed, with a minimum run size of 9,000-11,000 adults per year (King County and WRIA 9 2005). Kerwin and Nelson (2000) cited a variety of reports that listed a range of historic population estimates for Chinook salmon in the Green River basin. Historic annual spring Chinook run size estimates for the upper Green River basin (upstream of the Tacoma Diversion) ranged from150-300 adults per year (cited as Riseling 1913 and Grette and Salo 1986) to as high as 1,286 adults per year (cited as Chapman 1981).

Historically, Chinook spawning occurred from approximately RM 24 to RM 91, as well as in larger tributaries such as Newaukum Creek and tributaries in the Upper Green River (King County and WRIA 9 2005).

Since dam construction, the majority of natural Chinook salmon production occurs in the Middle Green River below the Tacoma Diversion, and in Soos and Newaukum Creeks (Kerwin and Nelson 2000). Although spring Chinook salmon (stream-type) are occasionally found in the Green River, they are found

in such low numbers that most biologists consider spring Chinook to be functionally extinct and they do not constitute a distinct stock in the Green River (Kerwin and Nelson 2000; Coffin et al. 2011). The recognized independent Chinook salmon population is the Green/Duwamish summer/fall Chinook stock (ocean-type), which now includes Newaukum Creek fish that were previously considered an independent stock (King County and WRIA 9 2005). Puget Sound Chinook salmon (including the Green River population) are listed as a threatened species under the federal ESA[1].

**Table 2. Historic and current salmonid spawning in the Lower Green River.**

| Species | Number of Spawners | | Reference |
|---|---|---|---|
| | Historic | Current | |
| Chinook salmon | 900 to 37,700 | NA | King County & WRIA 9, 2005 |
| Summer/fall | NA | 18,000 | WDFW 2014 |
| Naturally spawning summer/fall | NA | 796 to 11,558 | NOAA 2010 |
| Coho salmon | 5,400 to 6,200 | 700 to 12,500 | Kerwin and Nelson, 2000 |
| Newaukum Creek population | NA | 1,034 to 9,300 | Kerwin and Nelson, 2000 |
| Chum salmon | NA | 11,300 (avg) | Kerwin and Nelson, 2000 |
| Pink salmon | 1,000 | >1 million | WDFW 2012 |
| Sockeye salmon | NA | 100 to 400 | Kerwin and Nelson, 2000 |
| Winter Steelhead | 500 to 2,500 | NA | Kerwin and Nelson, 2000 |
| Native wild/hatchery supplement | NA | 950 to 2,750 | Kerwin and Nelson, 2000 |
| Early Winter hatchery | NA | 500 | Kerwin and Nelson, 2000 |
| Summer Steelhead | 0 to 3,398 | 600 | Kerwin and Nelson, 2000 |
| Bull Trout | A few | NA | Kerwin and Nelson, 2000 |
| Cutthroat Trout | NA | NA | Kerwin and Nelson, 2000, King County & WRIA 9, 2005 |

The Soos Creek Hatchery, operated by the Washington Department of Fish and Wildlife, raises and releases fall Chinook, coho, and summer and winter steelhead. The fall Chinook program goal is an integrated hatchery and natural population with hatchery fish primarily designated for harvest. Approximately 3,200,000 juvenile fall Chinook are produced annually leading to a return of over 18,000 adults (approximately 0.56% survival from smolt to adult). Approximately 1864 adults are required for brood stock and up to 16% of the brood stock are of natural origin. (All data from WDFW 2014b.)

Escapement for the natural spawning Green/Duwamish River summer/fall Chinook stock from 1986 to 1997 averaged 6,031 and ranged from 2,027 to 10,059 (Kerwin and Nelson 2000). Newaukum Creek summer/fall Chinook escapement from 1987 to 1997 averaged 1,135 adults, and ranged from 285 to 2,968 (Kerwin and Nelson 2000).

In 2004, three different Green River Basin natural Chinook salmon abundance estimates were summarized in King County and WRIA 9 (2005). These three basin-wide estimates of the existing adult natural Chinook salmon population levels vary by as much as 38 percent according to the methods and assumptions employed. Estimates vary depending on whether sport harvest and hatchery strays are included, with a range across estimates from 729 to 31,355 adult returns (generally from years 1968 to 2002). The mean return ranges from approximately 9,000 to over 14,000. The authors caution that none of these estimates incorporate WDFW spawning escapement analysis that suggests the traditional redd

[1] Puget Sound Chinook salmon were first listed as threatened on March 24, 1999 (64 FR 14308) and their threatened status was reaffirmed on June 28, 2005 (70 FR 37160).

count escapement estimates undercounted abundance by approximately 50 percent (King County and WRIA 9 2005). These estimates are higher than the earlier estimates from Kerwin and Nelson (2000).

The latest available spawner abundance estimates in the Green River for the run years 1968 through 2009 have ranged from a low of 796 (2009) to a high of 11,558 (1970) adults and averaged 5,924 adult spawners per year over this period (Figure 3-1; from NOAA 2014). The lowest return was in 2009, and the highest return between 2000 and 2009 was 8,321adults in 2004. The estimated fraction of wild fish has ranged from 26 to 66% since 2003 (since mass marking of hatchery fish began). Recovery objectives are to increase natural origin salmon to between 1,000 to 4,200 adults annually in the short-term (10-15 years) and increase natural original salmon to 27,000 over the long-term (50-100 years; King County 2012). The component of hatchery stock in the natural spawning population is large. A viable salmon population should have sufficient productivity of naturally produced spawners (not hatchery derived) in order to maintain population abundance above viability thresholds in the absence of hatchery produced fish (McElhany et al. 2000).

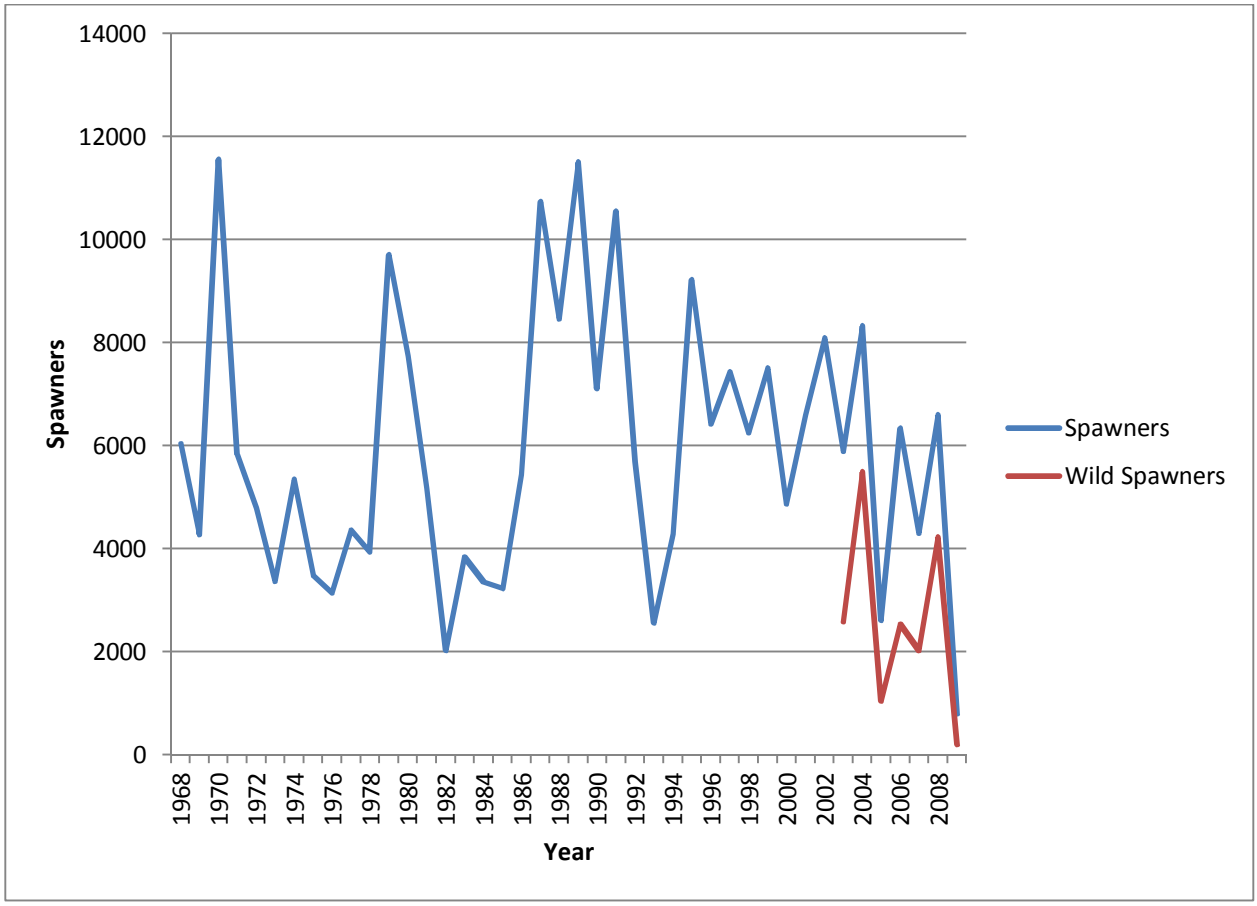


**Figure 3-1. Green River Chinook Estimated Spawners and Recent Fraction of Wild Spawners (from NOAA 2010).**

Current fish distribution maps show that Chinook spawning occurs starting at RM 25, and in the mainstem up to the Tacoma Diversion, as well as tributaries such as Soos and Newaukum Creeks. Juvenile Chinook salmon have been observed in Mill Creek (confluence with Green River at RM 24) (King

County and WRIA 9 2005), Mullen Slough (confluence at RM 22) and Springbrook Creek above the Black River Pump Station (confluence at RM 11) (WDFW 2014; Kerwin and Nelson 2000).

Juvenile summer/fall Chinook salmon in the Green River exhibit a bi-modal migration timing, with early migrants moving downstream shortly after hatching as fry (peak timing at WDFW screw trap at RM 34.5 in March), and likely rearing along the mainstem shorelines and any side-channels available in the Lower Green River and Duwamish Estuary as they progress towards the sea. The later parr migrants (peak timing at WDFW screw trap at RM 34.5 in June) have reared in habitats upstream near spawning grounds and migrate more rapidly to the sea in late spring and summer (WDFW 2012). Juvenile salmon in larger mainstem rivers such as the Green River are frequently associated with lateral, or margin habitat, which provides riparian-related cover as protection from predation and also provides low velocity shallow water refuge from swift mid-channel flows (R2 2001). Juvenile Chinook are well known for using floodplain habitats for extended rearing during their downstream journey. Floodplain habitats, including wetlands and side channels, provide protection from predation and frequently result in enhanced growth over individuals rearing in mainstem habitats (Sommer et al. 2001, Jeffries et al. 2008).

The 15-year trend in natural origin spawner abundance is less than 1.0, which means the population is continually declining (WRIA 9 2012), although it is difficult to predict exactly the status of the population. The mainstem habitat in the Lower Green River historically likely provided a substantially larger area of shallow shoreline and riparian fringe rearing habitat than currently exists; while the associated floodplain provided a vast area of high quality rearing habitat for out-migrant juveniles. The much reduced habitat available in the river is likely a factor of decline for the population.

### 3.1.1. Coho Salmon

Kerwin and Nelson (2000) cited a variety of reports that listed a range of historic population estimates for coho salmon in the Green River basin. Prior to the completion of the Tacoma Diversion, it was estimated that 9,000 to 25,000 coho salmon spawned in the upper Green River upstream of the Tacoma Diversion (Kerwin and Nelson 2000). Grette and Salo (1986, cited in Kerwin and Nelson 2000) estimated an annual coho escapement upstream of the Tacoma Headworks as 5,400 to 6,200 adults, while Chapman (1981, cited in Kerwin and Nelson 2000) provided a similar escapement estimate for upper Green River basin of 4,270 coho adults that produced an estimated 213,516 smolts annually.

Soos Creek Hatchery production of coho has a goal of an integrated hatchery and natural population with hatchery stock designated primarily for harvest. Approximately 555,000 juveniles are produced annually with approximately 45,000 adults returning (approximate 8.7% survival from smolt to adult). Approximately 1452 adults are required for brood stock and approximately 34% are of natural origin. (All data from WDFW 2014b.)

The coho salmon that enter the Green River Basin are composed of two stocks that have different spawning patterns (Kerwin and Nelson 2000). The Green/Duwamish stock returns to the Green River and Soos Creek in September and typically spawns to mid-November, while the Newaukum Creek stock spawns as late as mid-January. Escapement estimates for the Green/Duwamish River stock from 1967 to 1998 averaged 3,816 and ranged from 700 to 12,500. Spawning escapement estimates for the Newaukum coho stock for the years 1960 to 1996 averaged 5,029 adults per year, and ranged from 1,034 to 9,300 (Kerwin and Nelson 2000).

Juvenile coho salmon typically rear for one year prior to outmigrating as smolts. Coho juveniles are closely linked with woody debris cover in slow water habitats; off-channel habitats containing slow velocities and abundant instream cover are also important for juvenile survival over the winter months.

Such habitat was historically abundant in the Lower Green River floodplain prior to diversions, flow reductions, and levee construction (Collins & Sheikh 2005), and likely provided high growth rates and high overwinter survival for pre-smolt juveniles. Currently such habitat is largely lacking in the Lower Green River, although distribution maps show coho use of Mill Creek and possibly several smaller unnamed tributaries to the lower river (Kerwin and Nelson 2000, King County and WRIA 9 2005; WDFW 2014a). Overall, however, most rearing of juvenile coho is expected to occur in the Middle Green River and its principal tributaries due to high temperatures in the Lower Green River.

### 3.1.2. Chum Salmon

Historic run sizes and escapement estimates for chum salmon are more difficult to quantify. Williams (1975, cited in Kerwin and Nelson 2000 and King County and WRIA 9 2005) reported an average annual escapement for the Duwamish/Green River basin of 11,300 for the years 1966-71 inclusive.

The chum salmon that enter the Green River basin are separated into two stocks: Green River fall-run and Crisp Creek (also referred to as Keta Creek) fall-run chum salmon (Kerwin and Nelson 2000). Adults typically return to their natal rivers in the Puget Sound area in mid-September through mid-October (Kerwin and Nelson 2000). Unlike Chinook and coho salmon, chum salmon fry typically migrate downstream soon after emergence and rear in freshwater for a relatively short period. Despite this abbreviated rearing, habitat conditions encountered along the mainstem Green River during outmigration likely influence growth and survival of chum salmon smolts.

### 3.1.3. Pink Salmon

Pink salmon were historically reported in relatively small numbers in the lower and middle Green River basin. Fuerstenberg et al (Draft 1999, cited in Kerwin and Nelson 2000) estimated the historic pink salmon escapement as 1,000 adults in odd numbered years.

Williams et al. (1975) estimated that pink salmon were extinct from the basin. However, pink salmon runs on the Green River have increased dramatically in recent years. In 2001, an estimated 20,000 pink salmon entered the Green River, and in 2003, an estimated 300,000 pink salmon spawned. The 2013 preseason forecast was for the run of pink salmon in the Green River to be over 1.3 million fish (WDFW 2012). Juvenile pink salmon display similar life-history traits to chum salmon, with early emigration to the sea and abbreviated freshwater rearing.

### 3.1.4. Sockeye Salmon

Little historical information was obtained concerning early runs of sockeye salmon. Other than Lake Washington itself, Eagle Lake (sometimes referred to as Enapooh Lake), at 53.2 surface acres, is the only lake of sufficient size to have historically provided a rearing opportunity for lake rearing sockeye juveniles in this basin (Kerwin and Nelson 2000). Neither of the lakes is now accessible to anadromous fish via the Duwamish River.

Sockeye salmon adults are reported annually in the vicinity of the Tacoma Diversion, with estimates ranging from 100 to 400 adults (Kerwin and Nelson 2000). It is currently unknown if these fish are successfully reproducing since juveniles typically rear for extended periods in lakes prior to smolting and outmigration. However, the sockeye salmon seen each year on the spawning grounds could be river rearing sockeye, which we know very little about.

### 3.1.5. STEELHEAD

Kerwin and Nelson (2000) cited two reports (Riseland 1913 and Grette and Salo 1986) that estimated a historic escapement of 500 to 2,500 winter steelhead into the upper Green River (upstream of the Tacoma Diversion). Chapman (1981, cited in Kerwin and Nelson 2000), estimated a lower annual run size of 437 adult winter steelhead, that produced an average of 20,079 smolts per year.

There are currently three Green River basin winter steelhead stocks: a native wild spawning population, a hatchery supplementation program of the native stock and an early winter hatchery stock (Kerwin and Nelson 2000). Both the native Green River stock and the winter steelhead hatchery supplementation program were listed under the ESA in 2007 (NOAA 2007). Soos Creek Hatchery production of steelhead includes an integrated hatchery and natural winter steelhead population and a segregated summer and winter steelhead hatchery population. Approximately 33,000 winter steelhead juveniles are produced for the integrated population with an unknown return of adults. The production goal for the segregated populations are 30,000 juvenile summer steelhead and 68,000 juvenile winter steelhead, but the hatchery has produced more juveniles than the goal in recent years: approximately 98,000 summer steelhead and nearly 150,000 winter steelhead. The adult returns are approximately 600 and 500, respectively, for summer and winter steelhead (survival of 0.6% and 0.3%, respectively, smolt to adult). For the integrated population, the vast majority of adults used for brood stock are of natural origin (approximately 87%), whereas no natural origin adults are used in the segregated brood stock.

Hatchery steelhead typically spawn between January and March while the native stock spawns primarily between March and May. Natural spawner escapement estimates from 1978 to 2012 show moderate annual variation and have ranged from a low of 304 to a high of 2,778 fish per year. The lowest returns have occurred in the last five years (WDFW 2014b).

Summer steelhead in the Green River basin are near the edge of the geographic range for this species. The run size and estimated escapement of this species is not available. The best indication of a historic run comes from Washington Department of Fish and Wildlife harvest records (1962-1982), which ranged from 0 to 3,398 fish per year, and averaged 1,269 fish annually after the hatchery program was started (Kerwin and Nelson 2000). Harvest prior to the hatchery program was minimal.

Juvenile steelhead display a longer period of freshwater rearing than most other species, with one to three years of freshwater residence (King County and WRIA 9 2005). Although juvenile steelhead are not as dependent on off-channel habitats as are juvenile Chinook and coho salmon (Hartman and Brown 1987, Swales and Levings 1989), high quality slow-water margin habitat is important to small juveniles, while larger juveniles are typically associated with fast-water riffle and run habitats. High quality margin habitats and fast-water habitats are very limited in the Lower Green River, and are found primarily present in the upper reaches. However, fish distribution maps indicate some steelhead use of tributaries to the Lower Green River, including Mill Creek and Springbrook Creek (Kerwin and Nelson 2000).

### 3.1.6. BULL TROUT

Historical Information on the presence, abundance, distribution, use and life history of bull trout in the Green River basin is either unavailable or extremely limited (Kerwin and Nelson 2000). Pautzke and Megis (1940, cited in Kerwin and Nelson 2000) described the presence of a few Dolly Varden during the 1930's in the Green River.

Bull trout have been occasionally reported in the lower Green/Duwamish River, but data are insufficient to assess the status of this species. Bull trout are particularly intolerant of warm water temperatures, which impose strict limitations in suitable spawning and rearing habitat (Fraley & Shepard 1989,

Dunham et al. 2003). Consequently, most self-sustaining populations of bull trout are those with access to high quality headwater streams with cool, year-round temperatures. In the 1990s, sampling was conducted by Plum Creek Timber biologists above Howard Hanson Dam to look for a disconnected population similar to the Cedar River population (Berge and Mavros 2001). While they were unable to find any native char, they were not able to rule out the possibility that there were bull trout above Howard Hanson Dam.

### 3.1.7. Cutthroat Trout

No information was found regarding the historical distribution or abundance of cutthroat trout in the Green River Basin, and Kerwin and Nelson (2000), note that data are scarce on this species. Coastal cutthroat trout can be anadromous or resident. Anadromous coastal cutthroat can be found year-round in shallow marine waters. Adults return to spawn in freshwater from December through spring (sometimes as late as June). Juveniles generally migrate from freshwater to marine waters at two or three years of age (Trotter 1989).

Coastal cutthroat trout have been reported throughout the Green River basin, but few data are available concerning present abundance or whether the fish are anadromous or resident (King County and WRIA 9 2005; Kerwin and Nelson 2000). They have been observed on the mainstem river up to the headwaters and all major tributaries (King County and WRIA 9 2005).

## 3.2. Conclusion

Fish populations have been substantially reduced from historic population sizes. Populations of Chinook and steelhead have continued declining, even with actions being taken to recover listed species. The primary species on an increasing trend is pink salmon, which spend very limited time in freshwater. Much more effort on addressing the limiting factors in the lower river is warranted. Actions to improve habitat and water quality in the Lower and Middle Green Rivers will be very important to the recovery of Chinook salmon that tend to spend all of their time in freshwater in the mainstem Green River.

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# 4. CURRENT HABITAT CONDITIONS

The habitat assessment study area has been delineated into three reaches that have differing aquatic and riparian habitat characteristics. Reach 1 extends from RM 5.5 to 11, Reach 2 extends from RM 11 to 26, and Reach 3 extends from RM 26 to 34 (Figure 4-1). These reaches were based on distinct habitat conditions and opportunities for habitat restoration. For example, Reach 1 is the upper portion of the Duwamish River and may provide opportunities for riparian enhancements and creation of shallow-water habitat; Reach 2 encompasses the bulk of the highly urbanized areas where there are many needs for riparian enhancements and several opportunities for floodplain and/or side-channel/tributary enhancement and Reach 3 includes both urbanized areas and agricultural lands and the zone where salmon spawning begins; there are opportunities for in-channel, riparian, and floodplain restoration.

Aquatic habitats in the Lower Green River were assessed in 2004 by Anchor QEA (2004) and in 2013 by R2 Resource Consultants (2014) for the WRIA 9 committee. Key aquatic habitat types that are being tracked over time for salmon recovery include large wood, pools, spawning gravel, and slow-water channel edge. Current conditions described herein are primarily based on 2013 data (R2 Resource Consultants 2014). Slow-water edge habitat was not quantified and is a key data gap for understanding the potential capacity of the river to provide juvenile rearing habitat.

Floodplain habitats that are being tracked over time include the riparian zone (defined as extending 200 feet from the ordinary high water mark on each bank), wetlands, ponds, forested floodplain (beyond the 200 foot riparian zone), and unvegetated land cover.

This section describes the existing conditions of the various habitats in separate subsections: first by aquatic habitat unit types, then spawning gravel, large wood, off-channel floodplain habitats, and finally riparian vegetation.

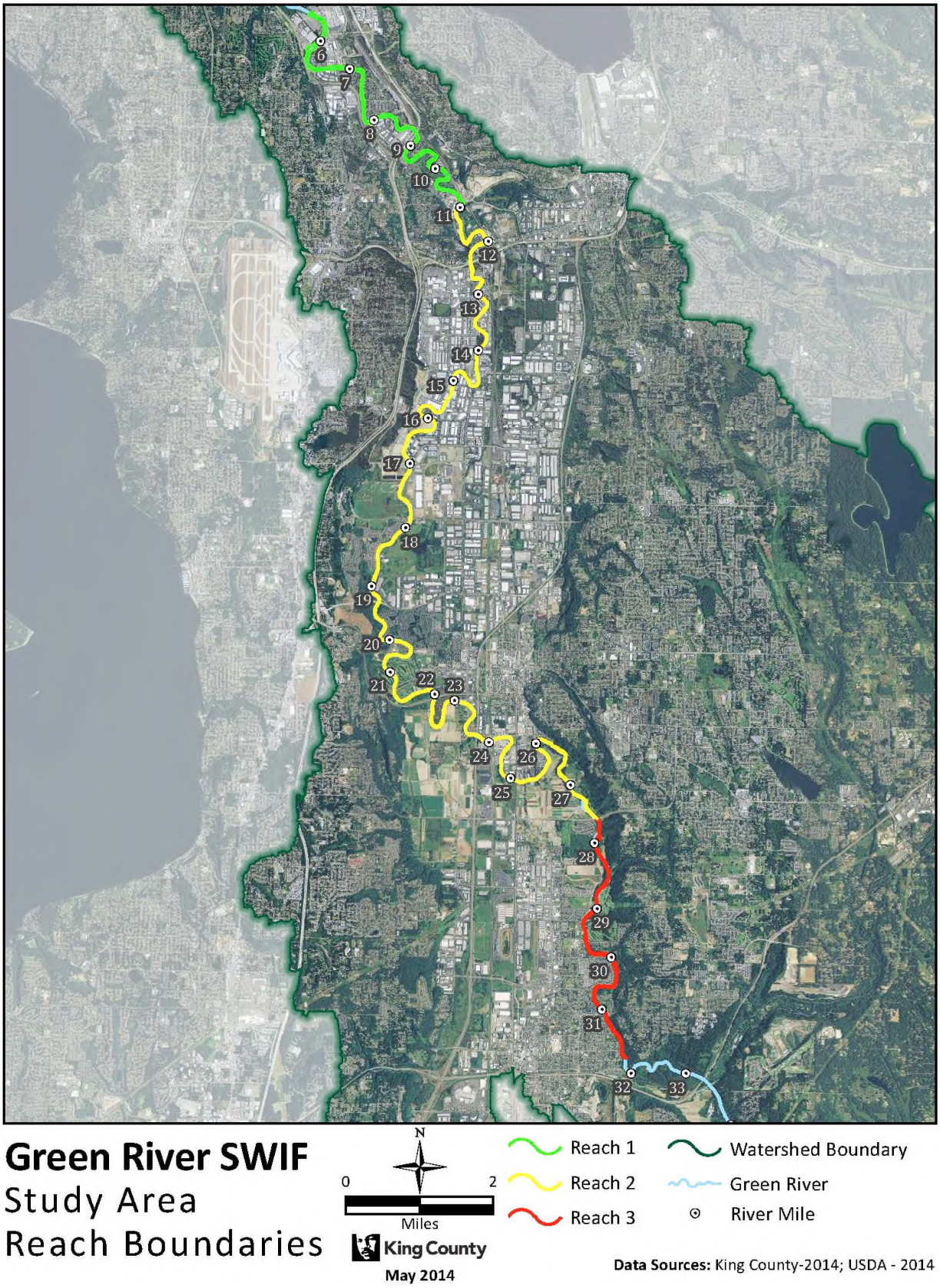



**Figure 4-1. Aquatic Habitat Assessment Study Area Reaches.**

### 4.1.1. In-stream Habitat Units

The Lower Green River is a low elevation, low gradient mainstem river segment. Major tributaries that enter the study area include the Black River/Springbrook Creek at RM 11, Mullen Slough at RM 21.7, and Mill Creek (Auburn) at RM 23.9. Several small unnamed tributaries also enter the Green River in the study area from both the west and east hill slopes. Conditions below RM 5.5 are not included in this memo.

The 2013 habitat assessment (R2 Resource Consultants 2014) evaluated glide, run, riffle, cascade, pool, and pocket estuary in-stream habitat units from RM 32.1 down to RM 0 at the mouth of the Duwamish River. The in-stream habitat in the study area is dominated by glides (88% of habitat area; Figure 4-2). Pools were infrequent (1% of habitat area). Riffles, runs, and backwaters comprised the remaining 11% of habitat area. Note that while the 2013 habitat assessment (R2 Resource Consultants 2014) defined pools the same as the 2003 assessment (Anchor QEA 2004), they found dramatically fewer pools in the lower Green River. The reason for this difference in the number of pools is not known, but two potential reasons are that they were collected at different flows and/or there were field interpretation differences between surveyors. Data from the 2012 bathymetry TIN provided by the Muckleshoot Indian Tribe (using a five foot residual pool depth), indicates that many of the pools mapped by Anchor QEA (2004) were still present and were missed in the recent surveys. To be inclusive, both data sets are described below.

In general, habitat is more complex at the upstream end of the study area, becoming increasingly uniform with distance downstream (Figure 4.2). For reference, the National Oceanic and Atmospheric Administration (NOAA) considers properly functioning stream habitat to have approximately 23 pools per mile for a channel width of 75 feet or more, and instream habitat types should be in fairly even proportions, not dominated by a single habitat type (NOAA 1996).

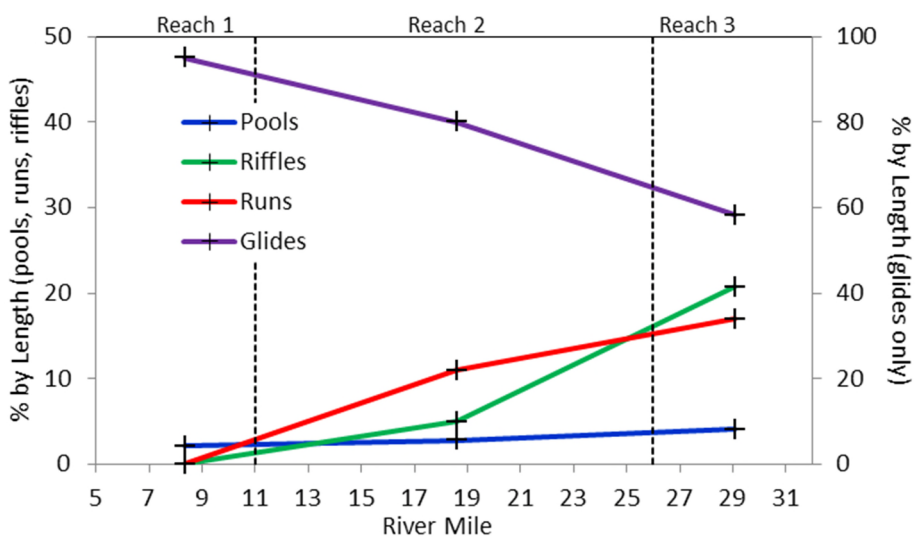



**Figure 4-2. Aquatic habitat distribution in the Lower Green River (data from R2 2014).**

Reach 1 (RM 5.5 to 11) is within the Duwamish River and is tidally influenced. Glides are the predominant habitat unit type (93%), with two backwaters (5%), two pools (2%), and a limited section of run (<1%) also present. Figure 4-3 shows the location of in-stream habitat units for Reach 1. The pools are located at RM 6.2 adjacent to the backwater described below (North Winds Weir) and at RM 10.3 on

a meander bend confined by riprap adjacent to the railroad line and Foster Golf Links. The short section of run is located at RM 10.2 in a relatively straight section. The backwaters are both recent restoration sites located at RM 6.2 (North Winds Weir) and 8.5 (Codiga Park), both on the right bank side, and each slightly over one acre in size. Additional deeper areas identified as pools in the 2003 assessment (Anchor QEA 2004) that were not mapped as pools in 2013 were located at RM 9.6, 9.8, and 10.6; all three were identified as associated with riprap scour. Over 20,000 linear feet of this reach is armored; approximately 35% of both banks (Anchor QEA 2004).

The in-stream habitat in Reach 1 is of low diversity and low quality. Pool habitat is extremely rare and limited in size. The once vast, intermixed system of wetlands has been essentially eliminated. Shallow water habitats, wetlands, and cover are primary missing elements. Due to the tidal nature of the reach, water velocities are fairly low; however, there are limited mud flats or shallow shorelines, marsh, or tidal delta and slough habitats that are used by juvenile salmon during their outmigration, particularly Chinook salmon. Use of delta habitat prior to entering saltwater can increase smolt to adult survival by increasing growth rates after juvenile Chinook enter the marine nearshore (Beamer & Larson 2004).

Key opportunities for restoration and enhancement in Reach 1 include riparian vegetation improvements (removing invasives and planting native trees and shrubs) where sufficient bank is available, sloping banks back to create shallow water habitat, placing additional wood or log jams specifically to form habitats (as opposed to bank protection), and creating alcoves and marshes. Locations could include RM 6-7 left bank (across from North Winds Weir site), RM 7-8 left bank along Green River Trail, RM 8 right and left banks in park areas, RM 8-9 left bank along Green River Trail, RM 9-11 near the golf course, and at the Black River confluence.

Reach 2 (RM 11 to 26) is a highly constrained and urbanized reach. Glides are again the predominant habitat unit type (80%), with several segments of run habitat (11%), a few very short riffles (5%), and eight pools (3%) also present. Figures 4-4 and 4-5 show the location of in-stream habitat units for Reach 2. The pools are located at RM 11.5, 12, 18.6, 21.3, 23.5, 24.2, and 24.8 (outside corner of Horseshoe Bend). The Riverview Park side-channel project at RM 23.5 has provided the only side-channel habitat available in the reach.

Additional deeper areas identified as pools in the 2003 assessment (Anchor QEA 2004), but not in 2013, were located at RM 11 (Black River confluence), 12.1, 13.2, 14.5, 16.2, 17.5, 18, 18.9, multiple small pools RM 19-20, multiple from RM 20-22 on bends, RM 22, 22.4, 22.5, 23, 23.8, and multiple locations from RM 24-26 on outside of Horseshoe Bend.

The instream habitat of Reach 2 is of slightly greater diversity than in Reach 1, but still of low diversity and quality. Deep pools are extremely rare and those pools that are present are limited in size. There are virtually no off-channel or floodplain areas that can be accessed and limited shallow water edge habitat. This reach has very poor shading conditions along the majority of its length. Armoring is present on over 72,000 linear feet of this reach (approximately 46% of the reach on both banks; Anchor QEA 2004).

Key opportunities for restoration and enhancement include riparian vegetation improvements (removing invasives and planting native trees and shrubs), sloping banks back to create more riparian area and shallow water habitat, placing additional wood or log jams for cover and pool formation, and floodplain and side-channel restoration, including creating off-channel or backwater habitats.

Reach 3 (RM 26 to 34) has more diversity of in-stream habitat types than the other two study reaches, with approximately 20% riffle, 58% glide, 17% run, and nearly 5% pool (by length). Figures 4-6 and 4-7 show the location of in-stream habitat units for Reach 3. The pools are located at RM 26.5, 27.5, 27.7, and 29. A recent levee setback project is present at RM 28.5 to 29 (Reddington).

Additional deeper areas identified as pools in the 2003 assessment (Anchor QEA 2004), but not in 2013, were located at RM 27.2, 27.9, 28.3, 28.4, 29.1, 29.4, 29.8, 30, 30.4, 30.5, 30.6, 31,9, and 32.

The instream habitat of Reach 3 is of moderate diversity, although of low quality in many areas. Deep pool habitat is extremely rare and limited in size. There are virtually no off-channel or floodplain areas that can be accessed and limited shallow water edge habitat. This reach has primarily fair shading conditions along the majority of its length. Armoring is present on over 24,000 linear feet (approximately 37% of the reach on both banks; Anchor QEA 2004).

Key opportunities for restoration and enhancement include riparian vegetation improvements (removing invasives and planting native trees and shrubs), sloping banks back to create more riparian area and shallow water habitat, placing additional wood or log jams for cover and pool formation, and floodplain and side-channel restoration, including off-channel or backwater habitats.

Although the focus is the Lower Green River, descriptions of the upper portion of reach 3 illustrates moderate quality habitat conditions for anadromous fish. Consequently, a brief description of the lower portion of the Middle Green River, which has been described as having the 'best" habitat for anadromous fish in the Green River Basin (King County and WRIA 9 2005) and successfully rears significant numbers of juvenile salmonids (R2 2001), is included here for comparison with the Lower Green River.

Habitat surveys conducted in 2001 (King County and WRIA 9 2005) indicated that pools comprised about 27% of the habitat area of the Middle Green River, versus only 5% in Reach 3 of the Lower Green River. More recent comparisons of pools and large wood (TPU 2011) indicates that while the Middle Green River had widely spaced pools, the pools that do occur are deep (> 8 feet) and frequently formed by wood. There are approximately 45 pieces of large wood per mile in the Middle Green and approximately 2.5 jams per mile (TPU 2011). The placement of wood by the Corps since 2004 is substantially increasing large wood and log jams between RM 57 and 61 and individual pieces have moved as far downstream as RM 39.5. Natural recruitment is also increasing (TPU 2011).

The increased gradient present in the Middle Green River also results in a higher frequency of riffle and run habitats and increased habitat complexity than in downstream reaches. Spawning gravel is significantly more abundant in the Middle Green River than in downstream reaches, as evidenced by the abundant open bars visible in aerial imagery. Gravel availability decreases again as one progresses upstream towards the dams, which interrupt sediment transport, but the USACE has been placing gravel downstream of the dams in recent years to supplement the supply.

The Middle Green River has less development than the Lower Green River, and more agricultural land with less impact on riparian vegetation. The riparian zone is much more continuous than in the Lower Green River, with more extensive forested floodplain. Side channels are also more abundant in the lower portion of the Middle Green River; at least 17 side channels are visible in aerial imagery, including one channel over 2,000 feet in length. Overall, the Middle Green River possesses much greater complexity of aquatic and riparian habitat, with far less human influence than the Lower Green River.

#### 4.1.1.1. Implications and Priorities

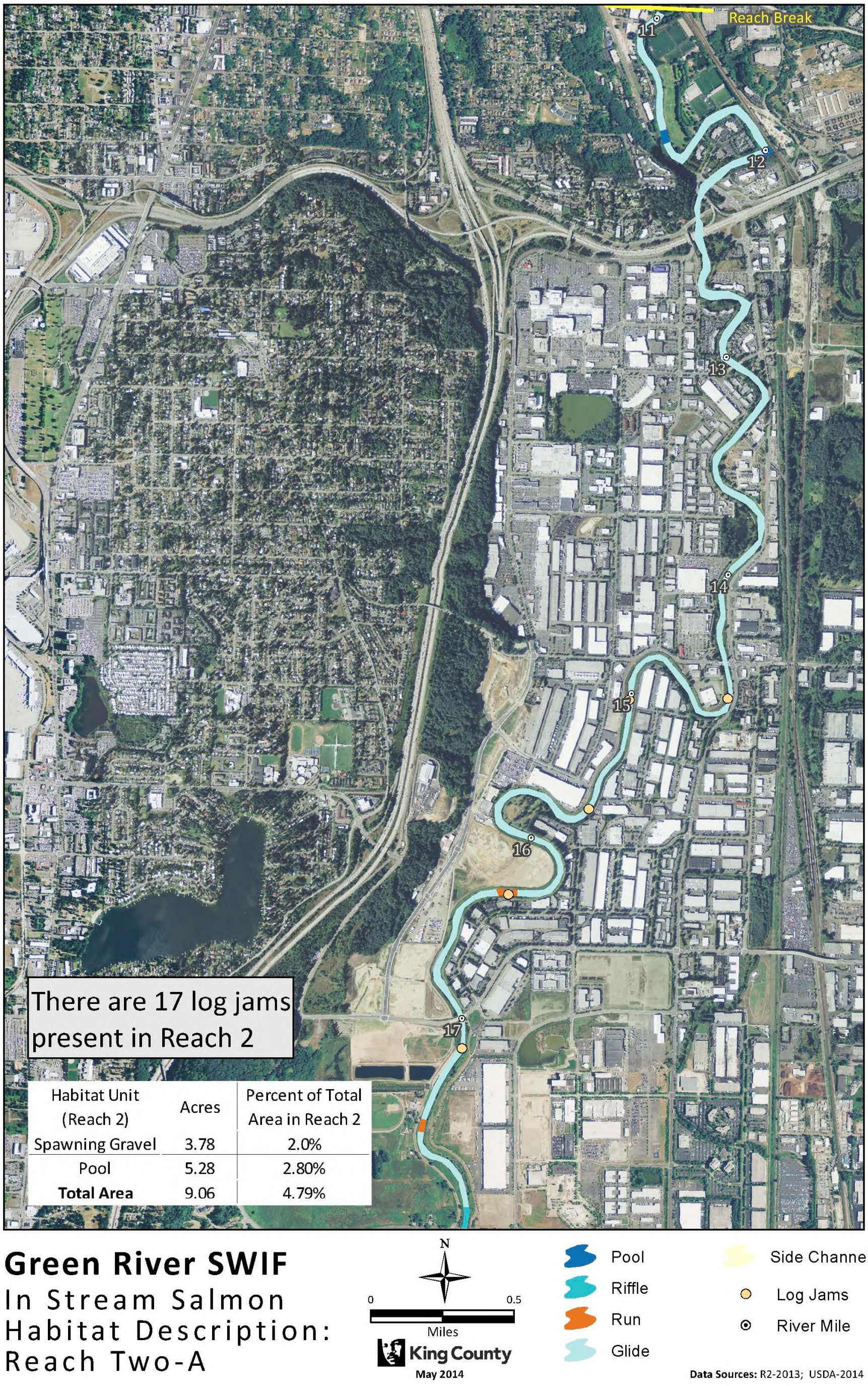
In-stream habitat diversity is low due to the confinement of the Lower Green River between levees and revetments, channel incision that has occurred over time due to sustained moderate-high flows from Howard Hanson Dam, and the lack of sediment and wood inputs. There is limited space to provide instream habitat features, but installing large wood that will promote additional pool formation as well as providing cover for existing pools is a critical high priority in the study area. Pools are important features for adult salmon for holding during their upstream migration; pools could also be constructed

to intercept groundwater or at tributary confluences to create localized slightly cooler areas for holding (R2 Resource Consultants 2010).

Shallow-water edge habitat is also a critical priority for the study area because it provides important rearing and refuge habitat for juvenile salmonids, particularly Chinook, as they migrate downstream. Shallow water provides habitat that larger predatory fish cannot access and provides rearing habitat for juvenile fish to grow to larger sizes before entering the Duwamish estuary. Vegetation overhanging the channel edge protects fish from birds and other predators from above, provides shade from solar radiation, and prey in the form of terrestrial insects to promote growth.

| Habitat Unit (Reach 1) | Acres | Percent of Total Area in Reach 1 |
|---|---|---|
| Pool | 3.7 | 3.1% |

**Figure 4-3. In-stream habitats present in Reach 1.**

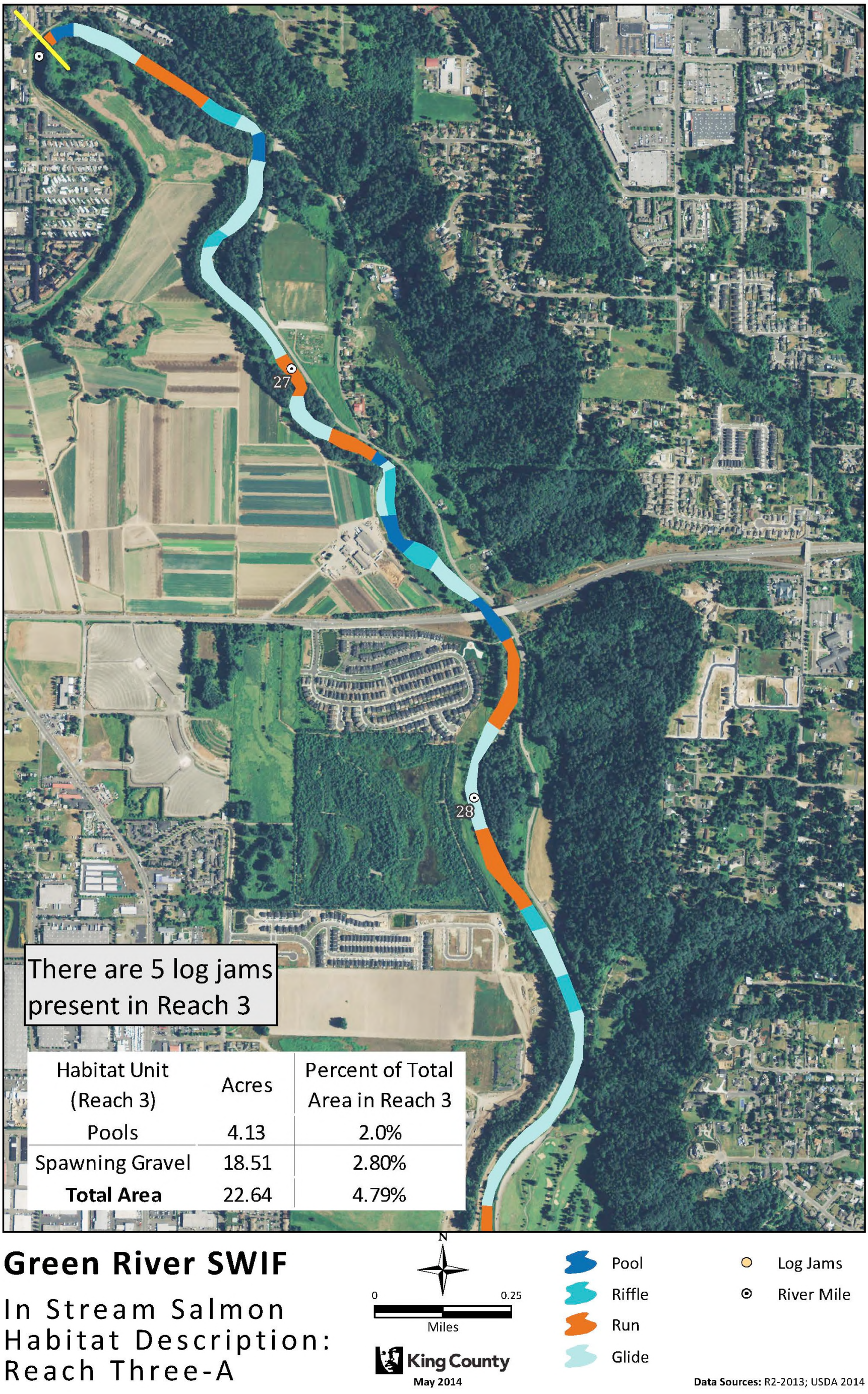



| Habitat Unit (Reach 2) | Acres | Percent of Total Area in Reach 2 |
|---|---|---|
| Spawning Gravel | 3.78 | 2.0% |
| Pool | 5.28 | 2.80% |
| **Total Area** | 9.06 | 4.79% |

**Figure 4-4. In-stream habitats present in the downstream half of Reach 2 (2A).**

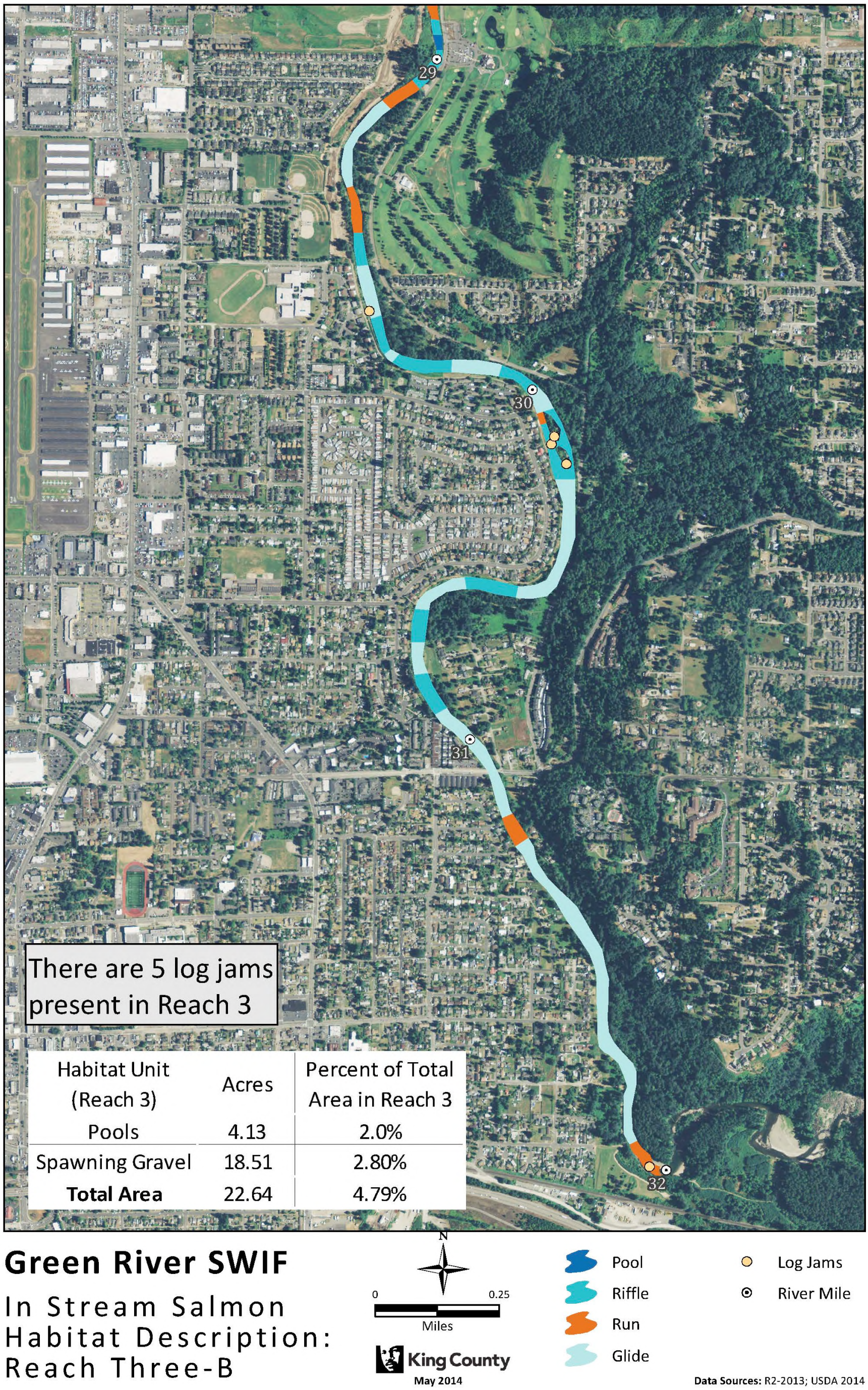
| Habitat Unit (Reach 2) | Acres | Percent of Total Area in Reach 2 |
|---|---|---|
| Spawning Gravel | 3.78 | 2.0% |
| Pool | 5.28 | 2.80% |
| **Total Area** | 9.06 | 4.79% |

**Figure 4-5. In-stream habitats present in the upstream half of Reach 2 (2B).**




| Habitat Unit (Reach 3) | Acres | Percent of Total Area in Reach 3 |
|---|---|---|
| Pools | 4.13 | 2.0% |
| Spawning Gravel | 18.51 | 2.80% |
| **Total Area** | 22.64 | 4.79% |

**Figure 4-6. Instream habitat in the downstream half of Reach 3 (3A).**




| Habitat Unit (Reach 3) | Acres | Percent of Total Area in Reach 3 |
|---|---|---|
| Pools | 4.13 | 2.0% |
| Spawning Gravel | 18.51 | 2.80% |
| **Total Area** | 22.64 | 4.79% |

**Figure 4-7. Instream habitat in the upstream half of Reach 3 (3B).**

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### 4.1.2. Spawning and Incubation Habitats

Gravels suitable for salmon spawning are typically found in riffles, runs, and pool tailouts. Using this simplistic definition, about 18.5 acres of suitable spawning gravel is present in Reach 3, and about 3.7 acres of suitable spawning gravel is present in the upstream-most portion of Reach 2. Pebble counts conducted in 2003 riffle habitats in Reaches 3 and 2 produced D50[2] values of 5 cm and 2 cm, respectively (Anchor Environmental 2004). Subsequent pebble counts conducted in 2013 produced D50 values of 2.9 cm and 2.2 cm, respectively (R2 Resource Consultants 2014), see Figure 4-8. Pebble counts could not be conducted below RM 23 due to the lack of riffle habitat and dominance of sand and silt substrates. Suitable substrate size for Chinook spawning ranges from 1.3 to 10.2 cm (Bell 1986).

Chinook salmon typically spawn in areas with water depths greater than 10 inches and water velocities of 1-3 feet/second (Bjorn and Reiser 1991). Coho, chum, and pink salmon and steelhead trout spawn in areas with similar depths and velocities, although coho and steelhead spawn more commonly in tributaries. Suitable temperatures for spawning typically range from 40 to 57° F (5 to 14° C; Bell 1986). The Washington Department of Ecology water quality standard (maximum) for salmon spawning is 63.5 F (17.5 C; Ecology 2011). Chinook have been documented spawning from RM 24.5 and on upstream through the Middle Green River (WDFW 2014a). Steelhead and pink salmon spawning is mapped as beginning at RM 27 and chum spawning begins at RM 29 (WDFW 2014a), although these species may spawn down to RM 24.5 similar to Chinook. The density of Chinook spawning is very low, only about 0.02 Standard Redd Density (SRD) in Reach 3 (King County and WRIA 9 2005).

Diversion of the White River, levee construction, and capture of upstream sediment at Howard Hanson Dam are primary factors associated with the loss of gravel habitat in the Lower Green River. The Corps has been adding spawning gravel to the river downstream of the Tacoma Diversion for the past several years. This material is slowly moving downstream and supplementing gravel supplies in the Middle Green River.

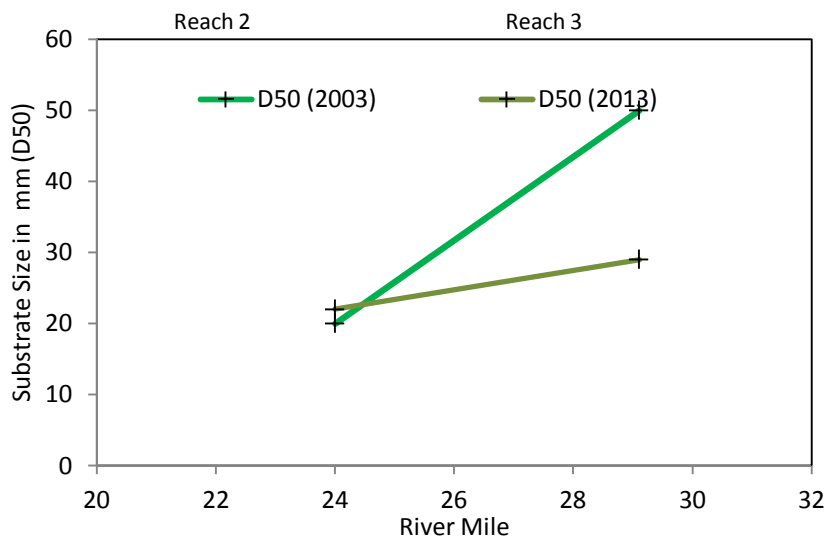


**Figure 4-8. Substrate size in riffles in the Lower Green River (from Anchor QEA 2004 and R2 2014).**

[2] D50 represents the median grain size of a sample; 50 percent is smaller and 50 percent is larger.

#### 4.1.2.1. Implications and Priorities

Spawning habitat is not a major component of the larger study area. Reach 3 of the Lower Green represents an area of historic spawning habitat that has been heavily degraded through many different historic actions. If fish population sizes increase due to recovery actions and the highest priority actions in the Middle Green are completed, improving the spawning habitat in the Lower Green will become important for reaching the longer term population recovery goals. The placement of large wood could provide sorting of coarser gravels in Reach 3 and enhance the small area of spawning habitat that occurs currently. Over the long-term, recruitment of suitable spawning gravels into the river is required to maintain spawning habitat. It is not clear whether gravel augmentation downstream of the Tacoma Diversion Dam will yield sufficient gravel to maintain spawning habitat in the Lower Green River. Allowing channel migration and sediment transport in the Middle Green River will be most conducive to providing a long-term source of gravel to the Lower Green River.

### 4.1.3. Large Wood

Large wood is present in all reaches, but at low numbers (R2 Resource Consultants 2014)[3]. In Reach 1, 234 pieces of wood and 2 log jams were counted, with approximately 50% of the individual wood and both log jams placed in revetments or other projects. In Reach 2, a total of 411 pieces of wood and 17 log jams were counted, with approximately 27% of the individual pieces and 100% of the jams placed as part of revetments or other projects. Thirty-five of the individual logs were placed in the recently constructed Riverview Park side channel. In Reach 3, a total of 120 pieces of wood and 5 log jams were counted; with approximately 40% of the individual pieces and jams placed as part of revetments or other projects. The three naturally formed log jams were located near RM 30.1 and are associated with a natural island complex, which is considered one of the most diverse and complex areas of habitat in the Lower Green River (R2 Resource Consultants 2014). However, on a per-mile basis, the large number of pieces of wood placed in Reach 1 now results in the highest number of pieces of wood per mile (Figure 4-9). For reference, NOAA defines properly functioning conditions for large wood as approximately 80 pieces/mile greater than 24 inches in diameter and greater than 50 feet in length (NOAA 1996).

[3] Large wood was defined in R2 (2002) using a modified protocol from the TFW Method Manual for LWD Surveys (Schuett-Hames et al. 1999). Debris jams must contain at least 10 pieces of wood that are in contact with each other.

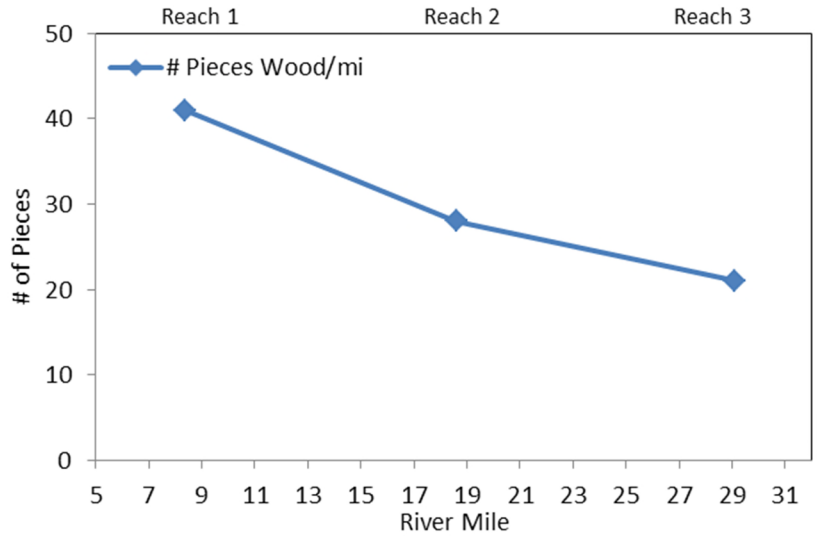


**Figure 4-9. Number of pieces of large wood in the Lower Green River (from R2 2014).**

#### 4.1.3.1. Implications and Priorities

There is limited large wood in the study area, with the majority having been placed recently in Reach 1 in restored backwater habitats, or the placement of wood into bank protection sites. Naturally occurring large wood provides cover, food web support, and helps form in-stream habitats such as pools and bars. The current configuration of much of the placed wood (linear configurations mostly providing only cover) in the Lower Green are not as effective as natural wood at improving habitat conditions. It is important to both place additional wood in Reaches 2 and 3 in more natural configurations to promote pool formation, and to restore forested riparian vegetation to contribute natural wood over the long-term to the system. Part of restoring the riparian area to be a source of LWD to the river also requires allowing some future channel migration or bank erosion to occur.

### 4.1.4. Off-Channel Floodplain Habitat

The combination of levee development, flow modifications, and reduced sediment and wood inputs following dam construction and diversion of the White River has led to almost complete elimination of the shallow slow-water edge, side channel, and wetland habitat that originally existed along the Lower Green River, as described in Section 2, previously (see Figure 3-1 and Table 2).

Only two side channels are currently evident based on aerial photos and habitat mapping: a 630 foot natural side channel with woody debris jams at RM 30 in Reach 3, and a constructed side channel 700 feet long at RM 23.5 in Reach 2. Combined, these side channels represent only about 1% of the length of the Lower Green River. Wetlands have been reduced by over 1,200 acres and are now highly fragmented into small parcels of low-lying woodlands, pastures, and farmed wetlands representing about 13% of the floodplain. Floodplain forest has been reduced by over 12,000 acres to about 8% of the floodplain, while ponds currently represent less than 1% of the floodplain. Developed lands now represent 74% of the floodplain (as compared to historic conditions when forested floodplain represented 75% of the floodplain), vastly reducing the potential habitat available for fish and wildlife (Figure 4-10). While these comparisons have been made with the historic floodplain that comprised 19,409 acres, the current mapped 100-year floodplain is now only about 1/3 of the size of the historic floodplain due to the diversion of the White River and the presence of Howard Hanson Dam.

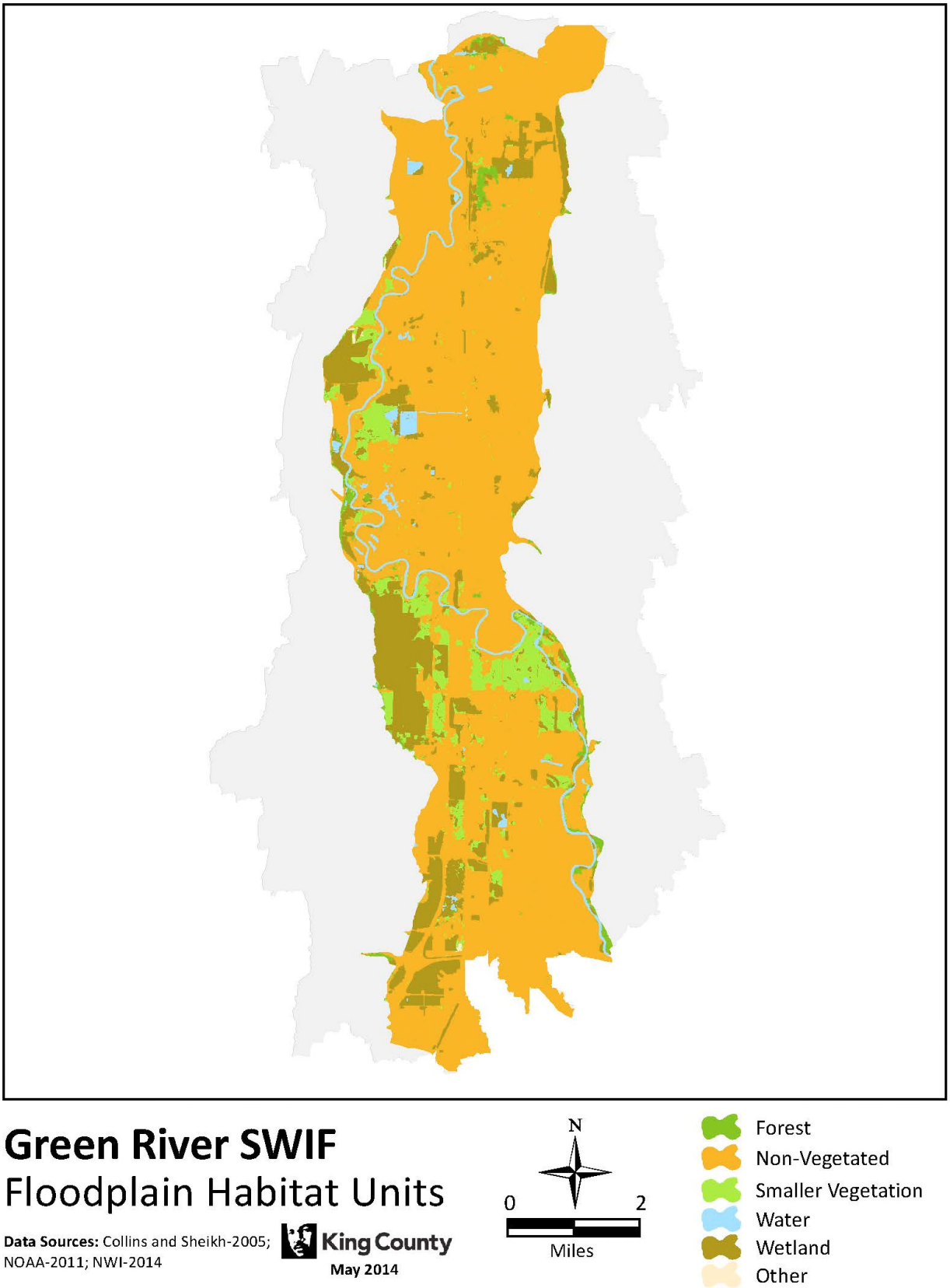


**Figure 4-10. Floodplain habitat types in study area.**

#### 4.1.4.1. Implications and Priorities

Floodplain and off-channel habitats are the most severely limited habitats in the study area. The Lower Green River has been transformed from a vast floodplain, wetland, and multiple channel complex into a single-thread channel with virtually no accessible floodplain. Reconnecting historic floodplain areas is a high priority. Setting back levees wherever feasible to reconnect areas of floodplain to high and low flows is one strategy for restoring floodplain connectivity; other options include creation of off-channel areas and modifying levee prisms to provide an inset floodplain. Enhancement and restoration of existing off-channel habitats associated with Springbrook Creek, Johnson Creek, Mullen Slough, and Mill Creek is also of high priority to provide refuge during winter and spring high flows and to contribute food web support (i.e. detritus, insects) and rearing opportunities for juvenile salmonids as they migrate downstream.

### 4.1.5. Riparian Vegetation

Vegetation and land cover maps for a 300-foot wide riparian corridor along both banks of the Lower Green River (RM 11 through 32) were created using aerial orthophotos (2009 and 2012) and LIDAR (2013). Polygons were digitized on screen and attributed according to the following vegetation and land cover classes:

- Bare Ground (non-vegetated, non-impervious surfaces)
- Grass (native and non-native grasses)
- Impervious surfaces (buildings, roads, parking lots)
- Other (drainage ponds, etc.)
- Shrubs (invasive and native)
- Trees (deciduous and conifer)

Using 2013 LIDAR high hit return information, all shrub and tree polygons were assigned an average height value. During the month of February 2014, field staff field verified vegetation mapping results. Additional field validation and classification of shrubs as invasive or native took place during spring 2014, and this information will be provided when available. Attributed vegetation and land cover data and maps for the Lower Green River riparian zone (defined as 200 feet from the river on each bank) were created using ESRI software. This geo-spatial information will be used in the development of alternatives and future phases of the Green River SWIF project.

For the entire study area from RM 11 to 32, Figure 4-11 and Table 3 show the vegetation types within the 200-foot riparian zone. The largest percentage of the riparian zone is occupied by impervious surfaces (27%) including roads, parking areas and buildings. The next most abundant cover type is trees (24%), followed by shrubs (19%) and grass (19%) of nearly equal proportion.

**Table 3. Riparian vegetation cover types for the study area.**

| Cover Type | Area (acres) | Percent of Total Area |
|---|---|---|
| Agriculture | 29.7 | 3% |
| Bare Earth | 37.4 | 4% |
| Grass | 196.2 | 19% |
| Impervious | 272.2 | 27% |
| Ornamental | 22.3 | 2% |
| Other | 18.1 | 2% |
| Shrub | 196.4 | 19% |
| Trees | 250 | 24% |
| **Totals** | **1,022.3** | **100%** |

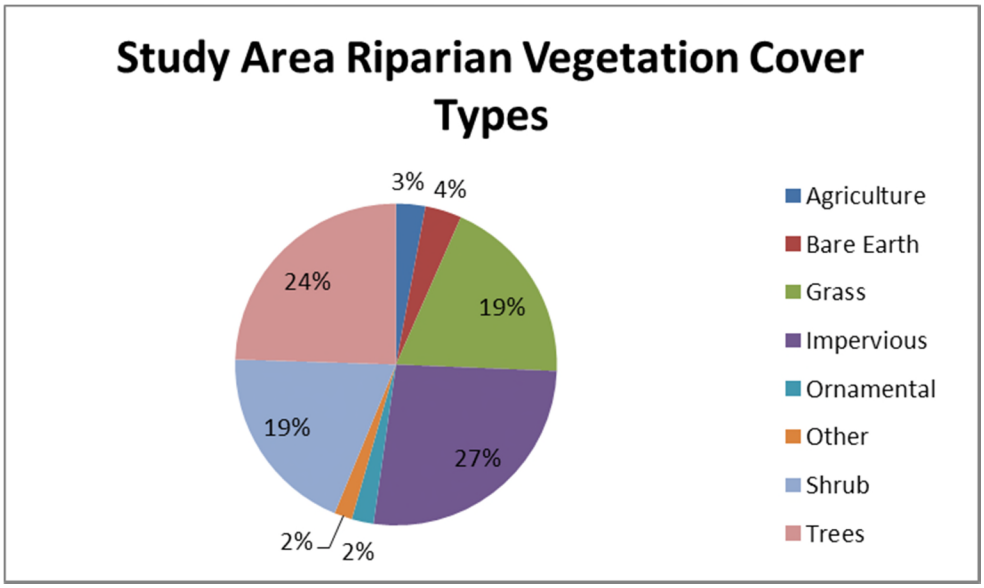


**Figure 4-11. Distribution of riparian cover types for the study area.**

#### 4.1.5.1. Riparian Vegetation in Reach 2

Riparian vegetation polygons were mapped for Reaches 2 and 3 (up to RM 32 only). Figure 4-12 shows the relative area and percentage of the vegetation types for Reach 2 overall. Four PL84-99 levee systems are located within Reach 2 and are also described below.

The Reach 2 riparian zone is dominated by impervious surfaces (31%), including roads, parking lots, and buildings. The second and third-most dominant cover types are grass (21%) and shrub cover (21%) with nearly equal proportion. Only 18% is tree cover. Patches of trees are typically rare and the majority of trees in Reach 2 are between 50-100 feet in height, but many areas only have trees less than 50 feet in height. The widest patches of trees extend about 100 feet from the river bank. The largest patch extends for approximately 3,500 feet along the left bank near RM 20, but is separated from the river by a road and revetments. Table 4 and Figures 4-13 and 4-14 show the riparian vegetation types and distribution for Reach 2 overall.

**Table 4. Riparian cover types for Reach 2.**

| Riparian Cover Type | Reach 2 (acres) | Percent of Reach 2 |
|---|---|---|
| Agriculture | 23.4 | 3% |
| Bare Earth | 32.2 | 4% |
| Grass | 156.3 | 21% |
| Impervious | 223.4 | 31% |
| Ornamental | 11.4 | 2% |
| Other | 2.2 | 0% |
| Shrub | 152 | 21% |
| Trees | 128.8 | 18% |
| **Totals** | **729.7** | **100%** |

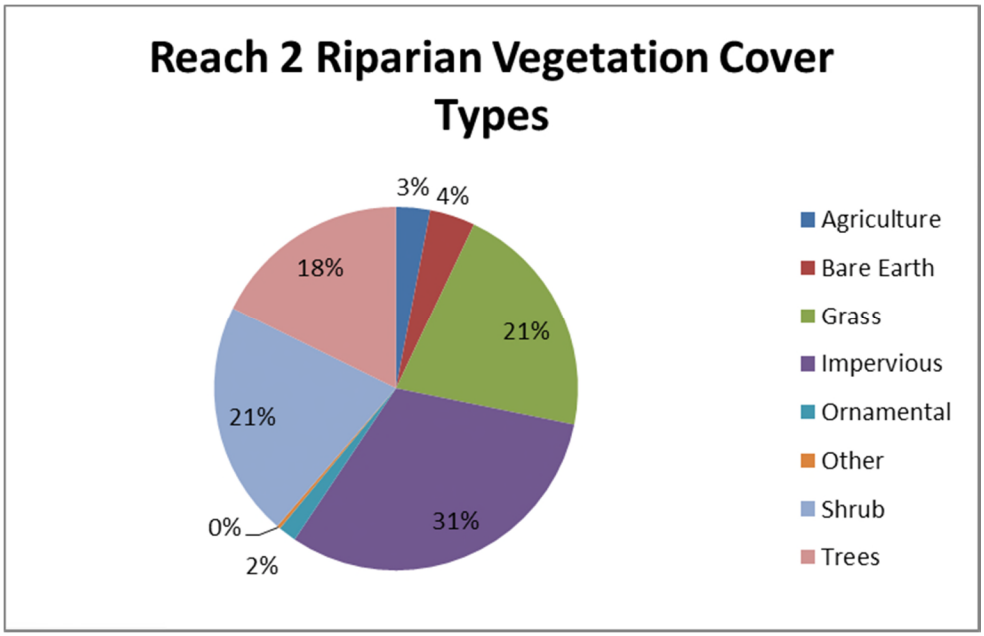


**Figure 4-12. Distribution of riparian vegetation cover types in Reach 2.**

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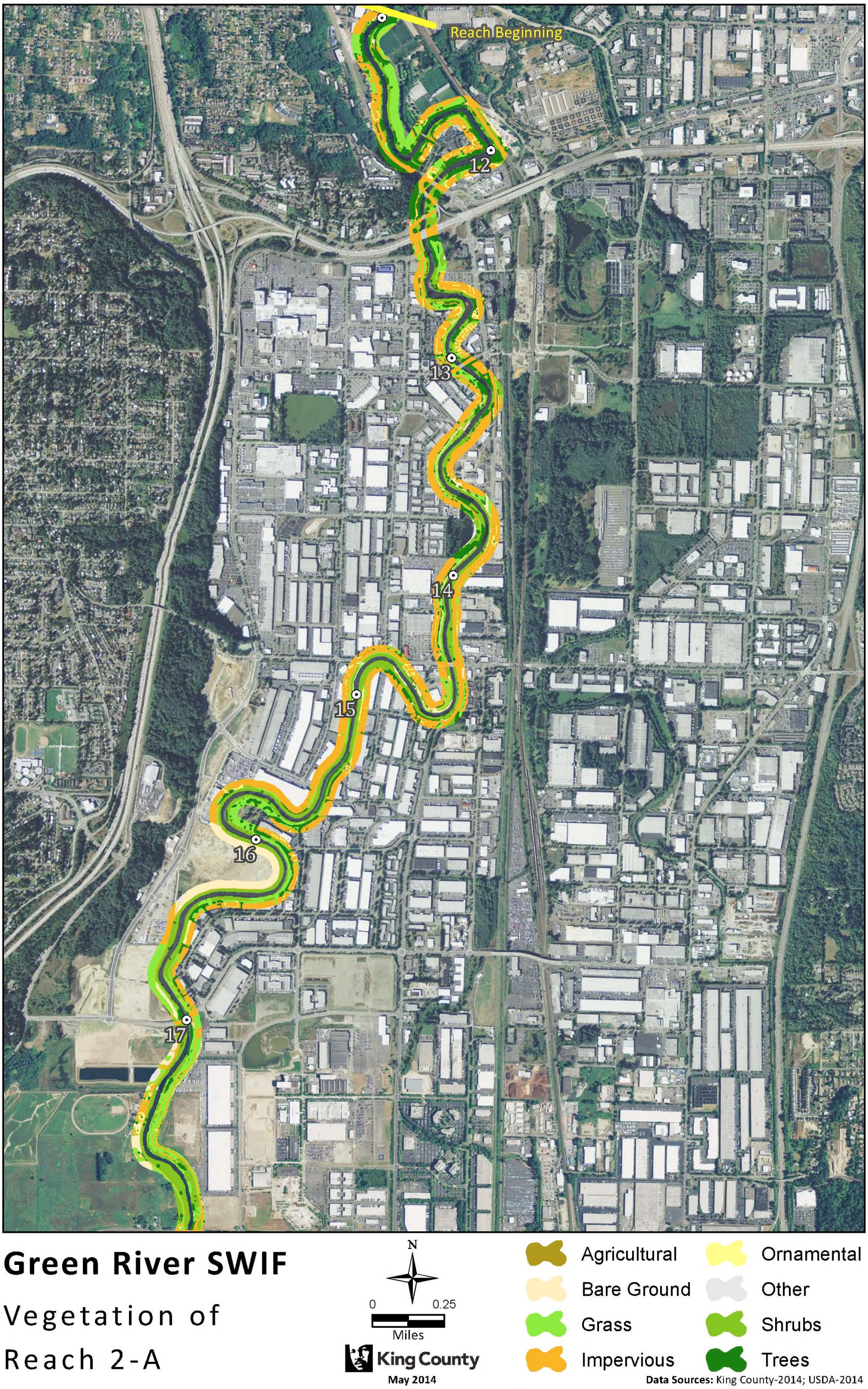



Figure 4-13. Riparian vegetation types in downstream half of Reach 2 (2A)

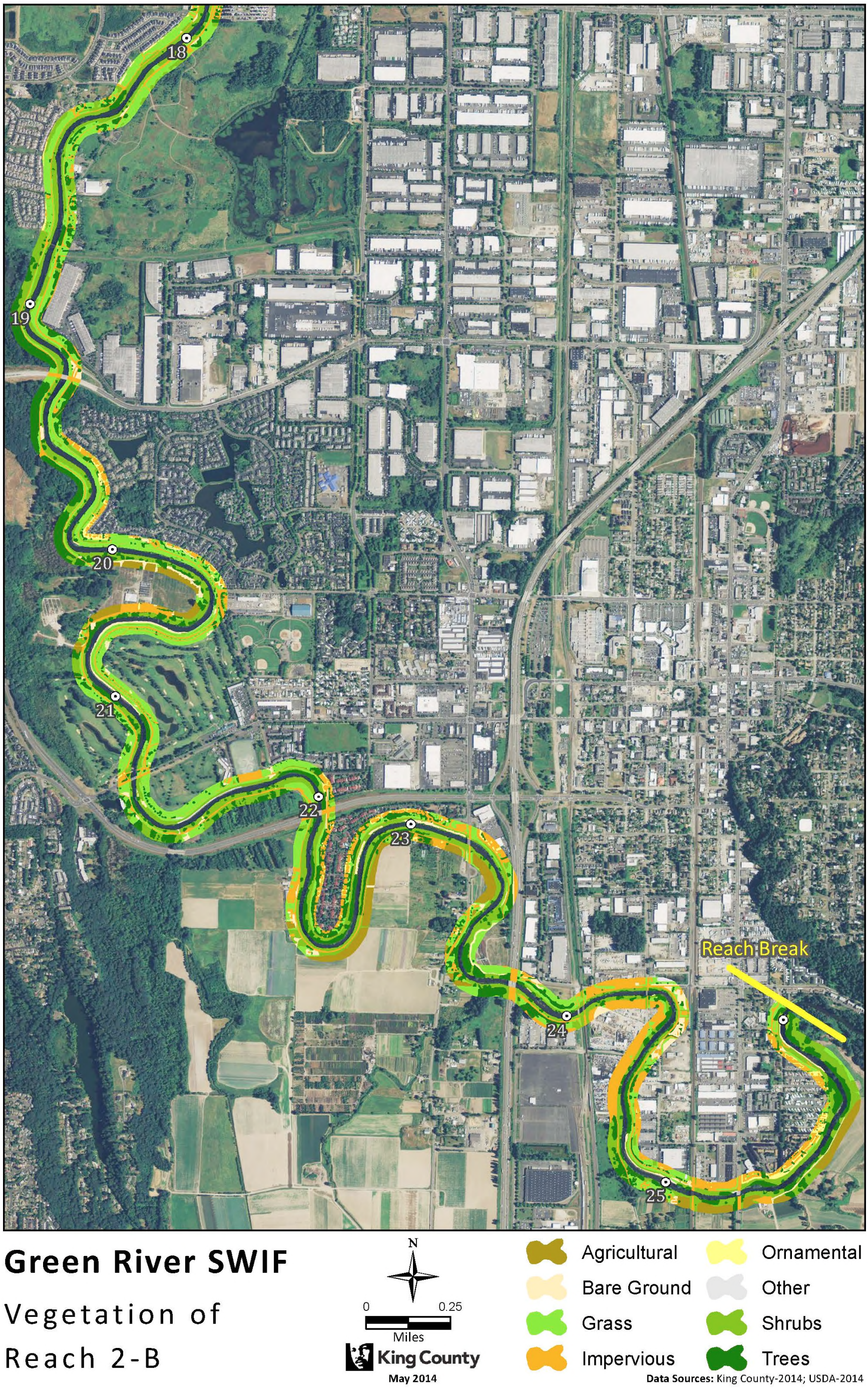



**Figure 4-14. Riparian vegetation types in upstream half of Reach 2 (2B).**

#### 4.1.5.1.1. Levee System #1. Tukwila 205, RM 12.44 – 16.7 (Left Bank)

The riparian vegetation on the PL84-99 levee systems differs from riparian vegetation in other parts of the study area and contributes to a larger percentage of the overall reduced riparian vegetation and effects on aquatic habitat evidenced in the Lower Green River. See Figure 1-3 for a graphic of where each levee system is located.

The Tukwila 205 levee system is located in Reach 2 on the left bank of the Lower Green River within Tukwila city limits and protects significant regional and local economic assets, including the Southcenter Mall and other commercial and industrial areas. The landscape behind the levee is highly urbanized, and approximately 47% of the 200-foot riparian zone is impervious surfaces. Riparian vegetation cover types are shown for this levee system in Table 5 and Figures 4-15 and 4-16.

Native tree cover is very sparse and there has been a substantial amount of tree cutting and willow thinning in the past decade per Corps and City of Tukwila requests. Two repairs have been completed recently (in 2008) and invasive vegetation was removed in those areas and native shrubs were planted, but on the majority of this levee, non-native blackberry and reed canary grass are dominant.

**Table 5. Riparian vegetation cover types for Levee System #1.**

| Riparian Cover Type | Levee System 1 (acres) | Percent of Levee Area |
|---|---|---|
| Agriculture | - | - |
| Bare Earth | 12.6 | 12% |
| Grass | 11.4 | 11% |
| Impervious | 48.1 | 47% |
| Ornamental | 1.6 | 2% |
| Other | 0.6 | 1% |
| Shrubs | 18.8 | 18% |
| Trees | 9.8 | 10% |
| **Totals** | **102.9** | **100%** |

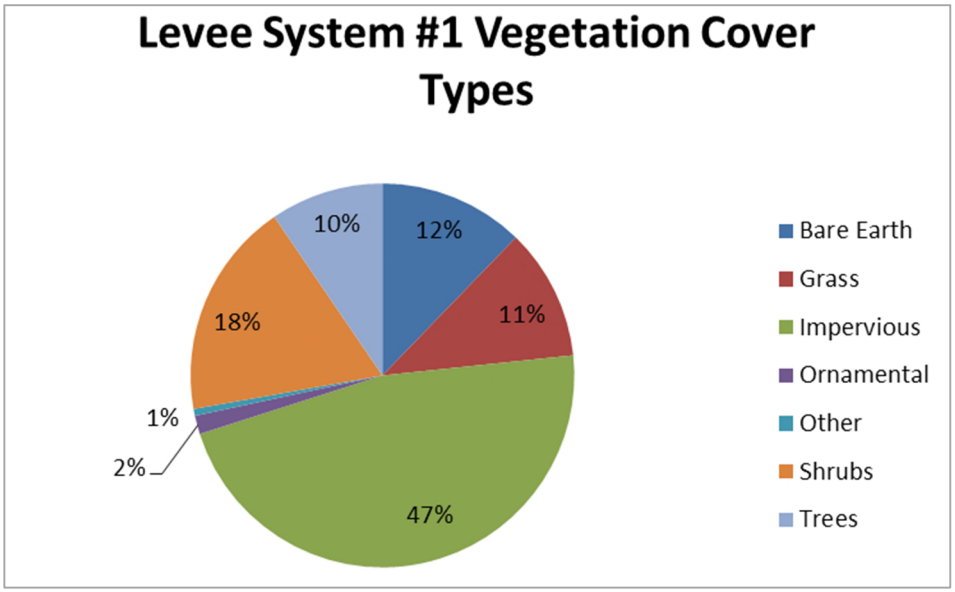



**Figure 4-15. Riparian cover types for Levee System #1, Tukwila 205.**

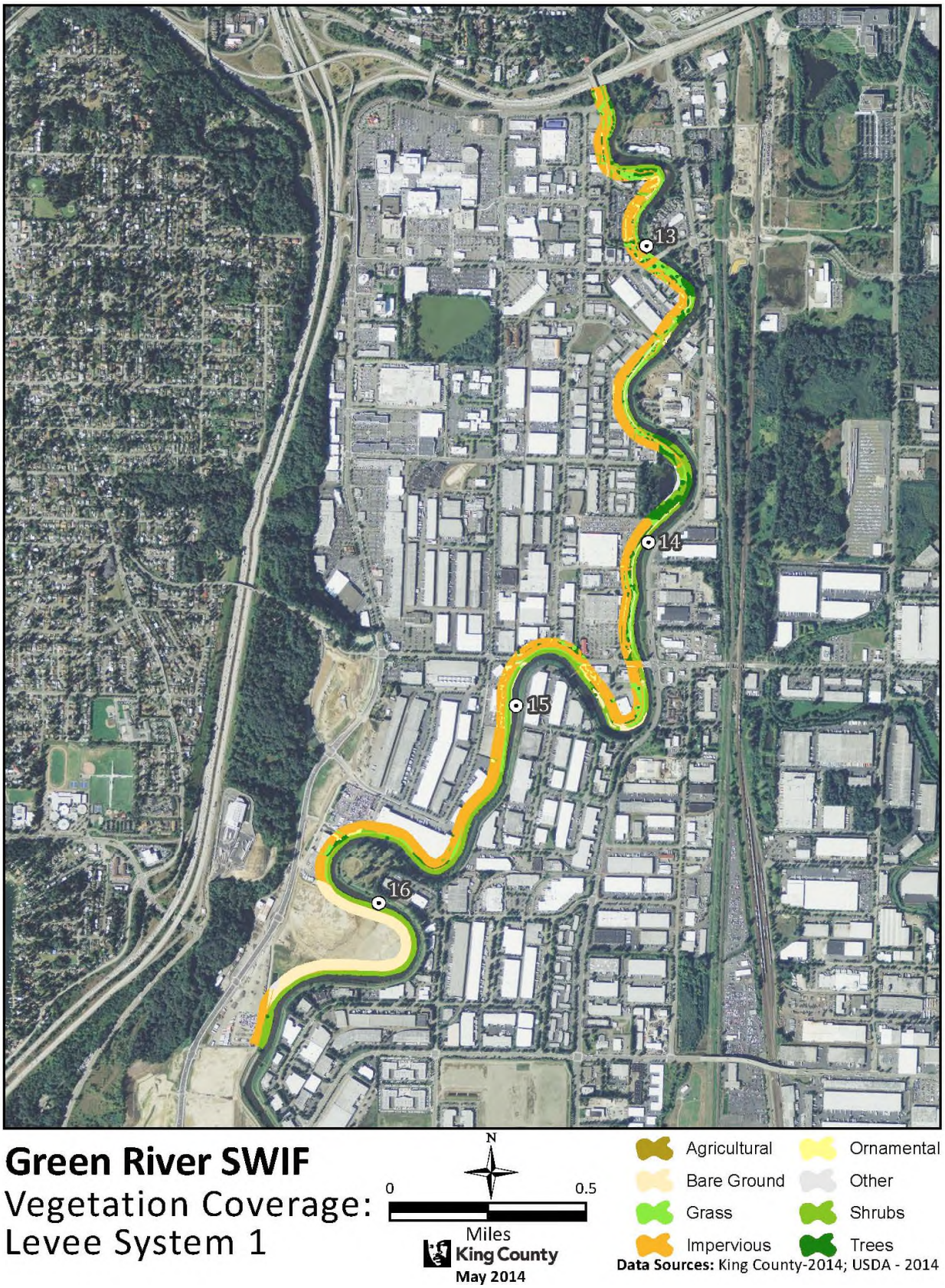



**Figure 4-16. Riparian vegetation polygons for Levee System #1, Tukwila 205.**

#### 4.1.5.1.2. Levee System #2, RM 14.5-22.04 (Right Bank)

Levee system #2 is comprised of six levee segments along the right bank: 1) Desimone-Briscoe School from RM 14.5 to 16.99; 2) Boeing levee from RM 16.99 to 17.83; 3) Lower Russell-Holiday Kennel from RM 18.28 to 19.28 4) Upper Russell-Somes Dolan from RM 19.27 to 20.35; 5) Kent Shops-Narita from RM 20.35 to 21.26 and 6) Meyers Golf levee from RM 21.3 to 22.04.

Riparian vegetation cover types are shown for this levee system in Table 6 and Figures 4-17 and 4-18.For levee system #2, 30% of land within the 200-foot riparian zone, totaling 40.3 acres is impervious surface – roads, parking lots, or buildings. The most dominant vegetation cover category is grass, with approximately 33% of the landscape. Shrubs comprise approximately 19% and trees approximately 15% of the levee system riparian zone. The majorities of trees are individual trees or rows of single trees, and are typically between 50 and 100 feet in height.

Where recent levee repairs have occurred, the non-native vegetation has been removed and reduced and native shrubs planted; but in areas where repairs have not occurred, the vegetation is dominated by non-native blackberry and reed canary grass.

**Table 6. Vegetation cover types for Levee System #2.**

| Vegetation Cover Type | System 2 (acres) | Percent of Levee Area |
|---|---|---|
| Agriculture | - | - |
| Bare Earth | 1.2 | 1% |
| Grass | 44.2 | 33% |
| Impervious | 40.3 | 30% |
| Ornamental | 2.7 | 2% |
| Other | 0.1 | 0% |
| Shrubs | 24.6 | 19% |
| Trees | 19.7 | 15% |
| **Totals** | **132.8** | **100%** |

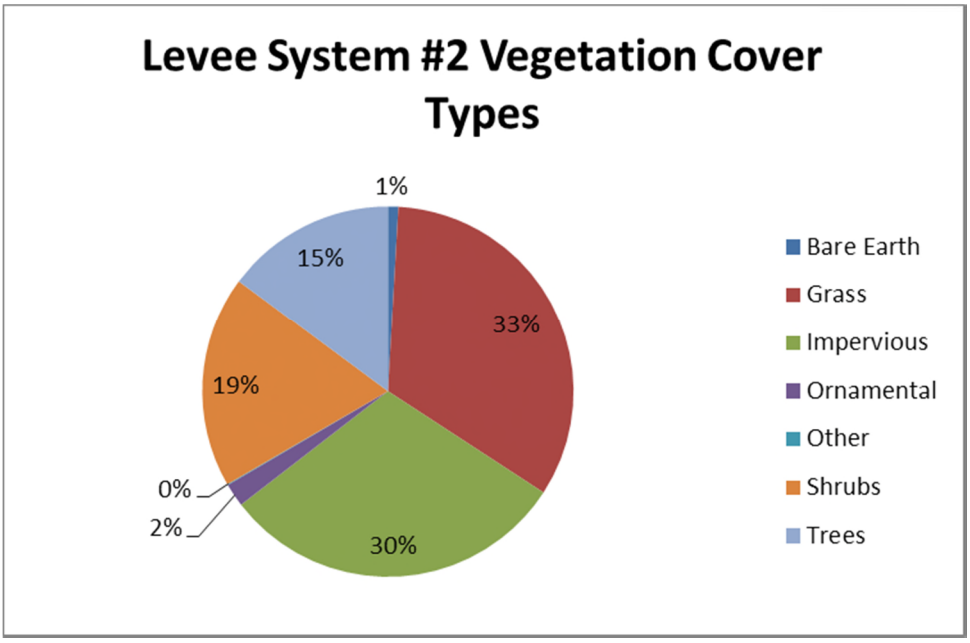



**Figure 4-17. Distribution of vegetation cover types for Levee System #2.**

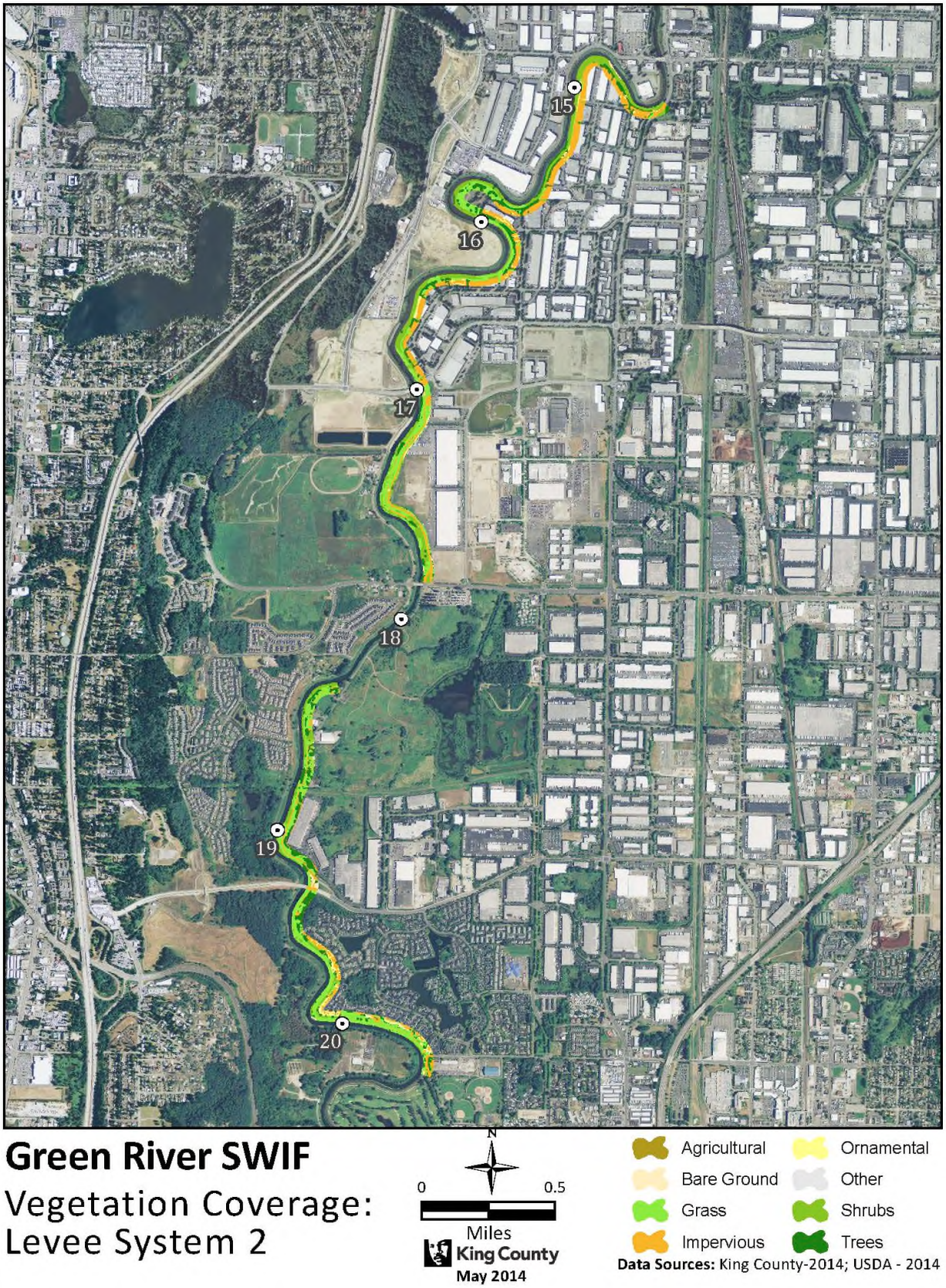



**Figure 4-18. Riparian vegetation polygons for Levee System #2.**

#### 4.1.5.1.3. Levee System #3, Signature Point, RM 22.77-23.18 (Right Bank)

Levee system #3 is comprised of the Signature Point levee on the right bank from RM 22.77 to 23.18, and primarily protects a golf course and a large apartment complex, plus other commercial and residential areas.

Riparian vegetation cover types are shown for this levee system in Table 7 and Figures 4-19 and 4-20.For levee system #3, approximately 23% of land within the 200-foot riparian zone, totaling 16.9 acres is impervious surface – roads, parking lots, or buildings. Approximately 34% of the vegetation cover is grass, approximately 16% is shrubs, and approximately 19% is trees. The shrub cover is dominated by non-native blackberry and the grass cover is dominated by reed canary grass or mowed grass (golf course). The tree cover occurs primarily at the apartment complex as single lines of trees (typically less than 50 feet in height).

**Table 7. Vegetation cover types for Levee System #3, Signature Point.**

| Vegetation Cover Type | System 3 (acres) | Percent of Levee Area |
|---|---|---|
| Agriculture | - | - |
| Bare Earth | 4 | 6% |
| Grass | 24.7 | 34% |
| Impervious | 16.9 | 23% |
| Ornamental | 0.8 | 1% |
| Other | 0.3 | 0% |
| Shrubs | 11.7 | 16% |
| Trees | 13.9 | 19% |
| **Totals** | **72.3** | **100%** |

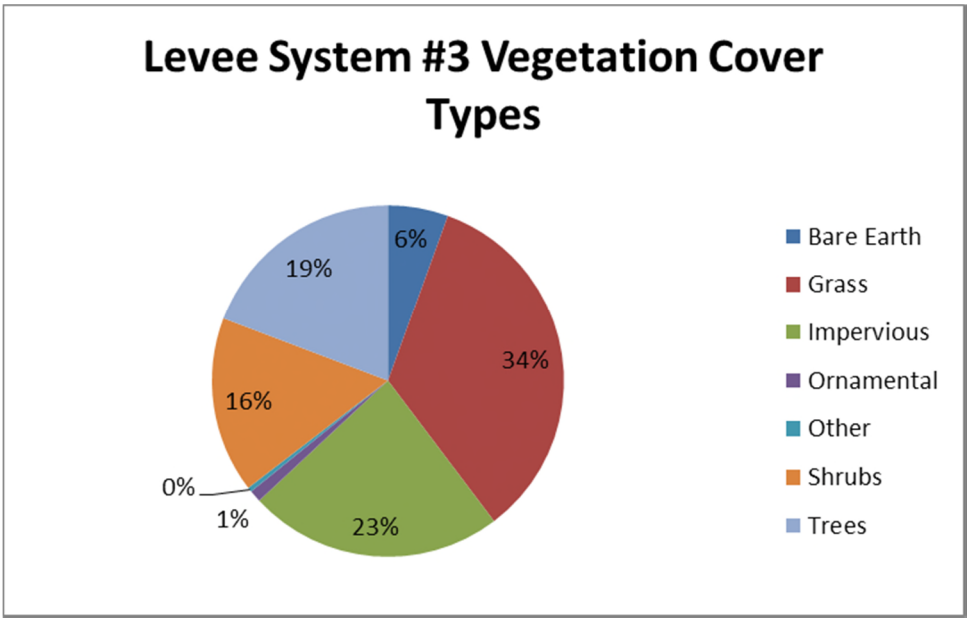



**Figure 4-19. Distribution of vegetation cover types for Levee System #3.**

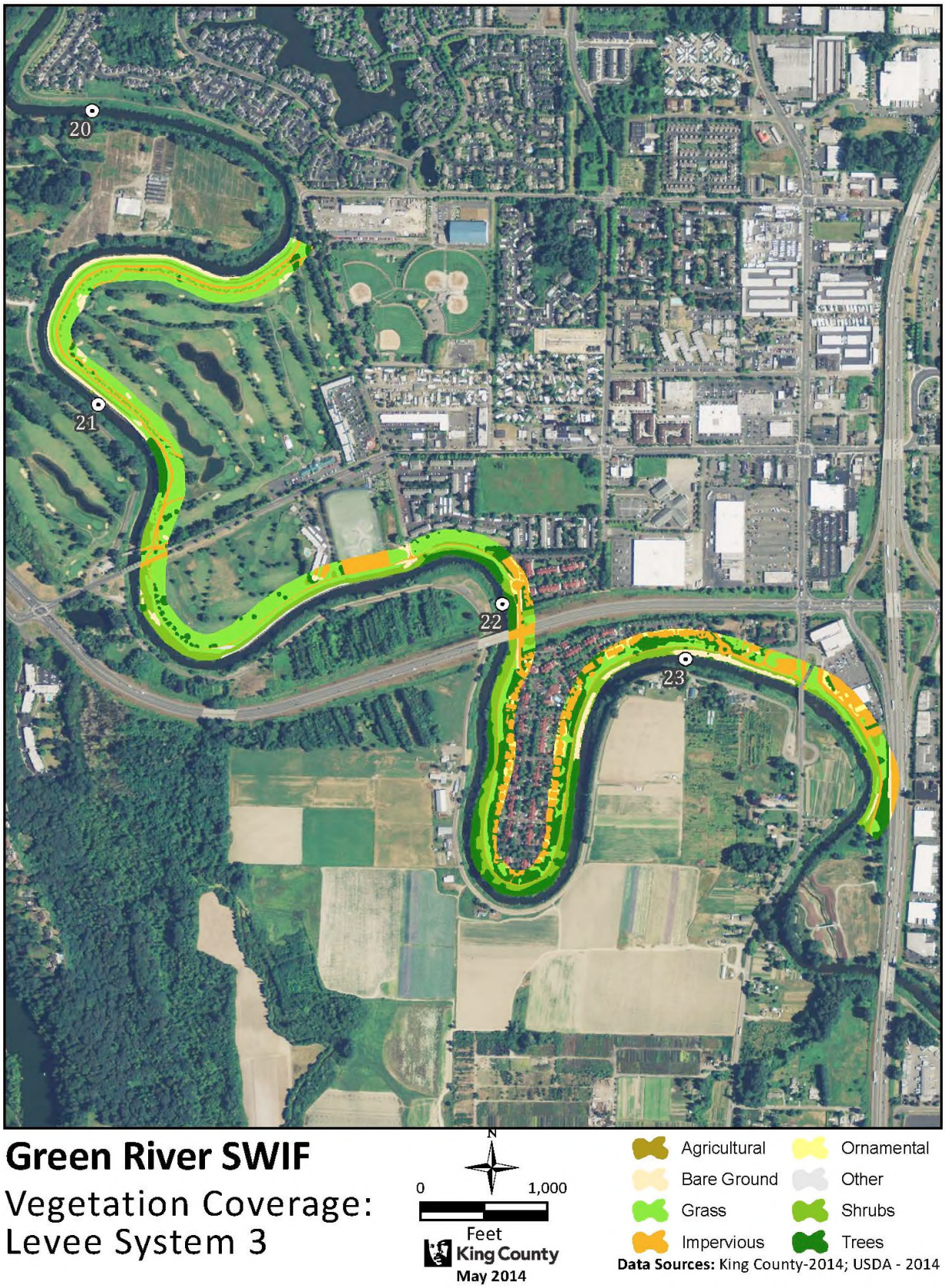



**Figure 4-20. Riparian vegetation polygons for Levee System #3.**

#### 4.1.5.1.4. Levee System #4, Horseshoe Bend, RM 24.25-26.09 (Right Bank)

Levee system #4 is comprised of the Horseshoe Bend levee on the right bank from RM 24.25 to 26.09. This levee system protects a variety of mixed land uses including commercial, light industrial, and a mobile home park. Riparian vegetation cover types are shown for this levee system in Table 8 and Figures 4-21 and 4-22. For levee system #4, approximately 38% of land within the 200-foot riparian zone, totaling 17.9 acres is impervious surface – roads, parking lots, or buildings. Approximately 16% of the vegetation cover is grass, approximately 19% is shrub, and approximately 16% is trees.

Trees are typically less than 50 feet in height – recent plantings have all been shrub species. The grass and shrub cover is dominated by non-native blackberry and reed canary grass.

**Table 8. Vegetation cover types for Levee System #4.**

| Vegetation Cover Type | System 4 (acres) | Percent of Levee Area |
|---|---|---|
| Agriculture | - | - |
| Bare Earth | 3.3 | 7% |
| Grass | 7.3 | 16% |
| Impervious | 17.9 | 38% |
| Ornamental | 1.9 | 4% |
| Other | 0.4 | 1% |
| Shrubs | 8.7 | 19% |
| Trees | 7.5 | 16% |
| **Totals** | **47** | **100%** |

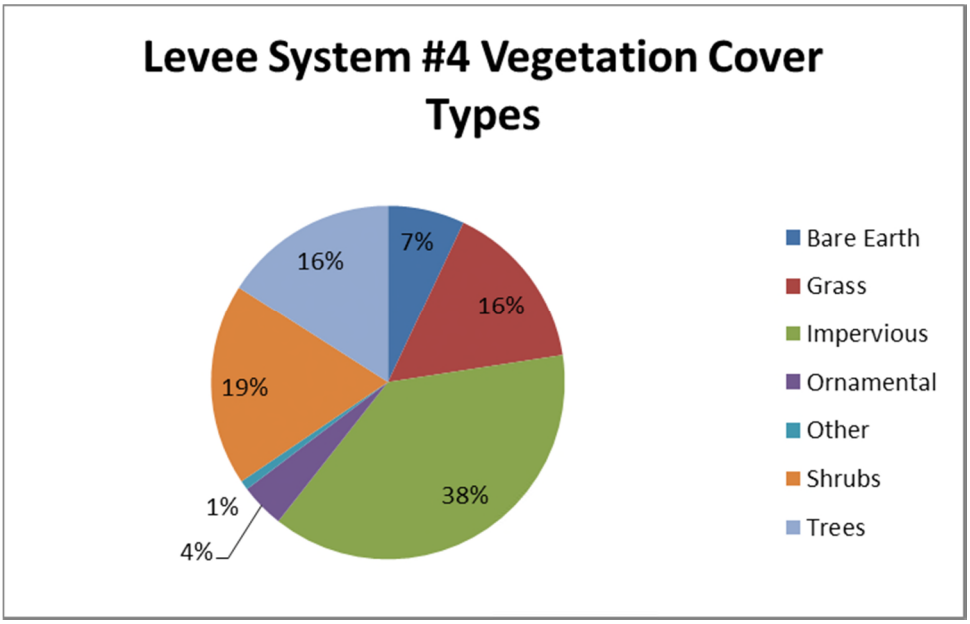



**Figure 4-21. Distribution of vegetation cover types for Levee System #4.**

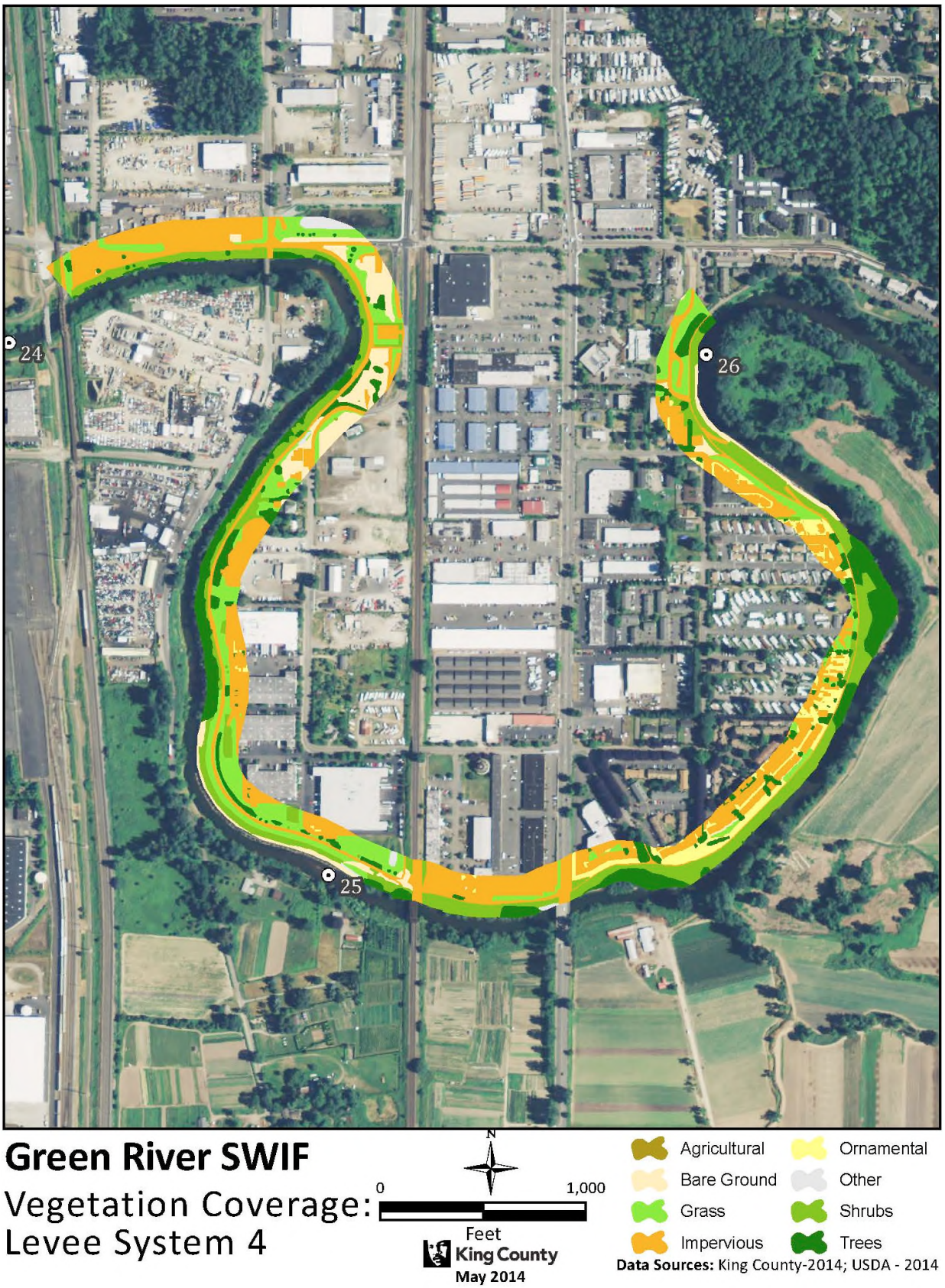



**Figure 4-22. Riparian vegetation polygons for Levee System #4.**

Table 9 shows how the riparian vegetation cover types compare between the PL84-99 levee systems and the rest of the Reach 2 riparian zone and the percentage that the PL84-99 levees occupy of Reach 2 for each cover type. The PL84-99 levee systems occupy approximately 50% of the riparian zone in Reach 2. The bare earth, grass, impervious, ornamental, and other cover types are more predominant in the PL84-99 levee system than in the reach as a whole, while the shrub and tree cover types are less predominant in the levee systems than in the reach as a whole.

**Table 9. Riparian vegetation cover types on PL84-99 levees compared to Reach 2 as a whole.**

| Riparian Cover Type | Reach 2 (acres) | Percent of Reach 2 | PL84-99 Levee Systems in Reach 2 (acres) | PL84-99 Percent of Reach 2 |
|---|---|---|---|---|
| Agriculture | 23.4 | 3% | -- | -- |
| Bare Earth | 32.2 | 4% | 21.1 | 66% |
| Grass | 156.3 | 21% | 87.6 | 56% |
| Impervious | 223.4 | 31% | 123.2 | 55% |
| Ornamental | 11.4 | 2% | 7.0 | 61% |
| Other | 2.2 | 0% | 1.4 | 64% |
| Shrub | 152 | 21% | 63.8 | 42% |
| Trees | 128.8 | 18% | 50.9 | 40% |
| **Totals** | **729.7** | **100%** | **362.3** | **50%** |

#### 4.1.5.2. Riparian Vegetation in Reach 3

Reach 3 includes one PL84-99 levee system. The Reach 3 riparian zone is dominated by trees (41%), then impervious surfaces (17%) and shrubs (15%) as shown in Table 10 and Figure 4-23. In Reach 3, the forested riparian areas are typically between 50-100 feet in width along the closest 100 feet to the river. It is rare that tree patches extend the entire 200-foot width of the riparian zone. Patches of trees are typically 50-100 feet in height and extend from 800 to over 6,000 feet along the river, but have gaps of 1,000 feet or more between patches. The right bank has much more forested riparian zone than the left bank, which means that many of the trees provide less shading benefits due to long sun exposure from the west. Figures 4-24 and 4-25 shows the riparian vegetation polygons for Reach 3. Figure 4-26 shows a representative section of Reach 3 with tree heights shown – the majority of trees are between 50-100 feet in height (approximately 46 acres), with only 5 acres greater than 100 feet and 7 acres less than 50 feet.

**Table 10. Riparian vegetation cover types in Reach 3.**

| Riparian Cover Type | Reach 3 (acres) | Percent of Reach 3 |
|---|---|---|
| Agriculture | 6.3 | 2% |
| Bare Earth | 5.2 | 2% |
| Grass | 39.9 | 14% |
| Impervious | 48.8 | 17% |
| Ornamental | 10.9 | 4% |
| Other | 16 | 5% |
| Shrub | 44.4 | 15% |
| Trees | 121.2 | 41% |
| **Totals** | **292.7** | **100%** |

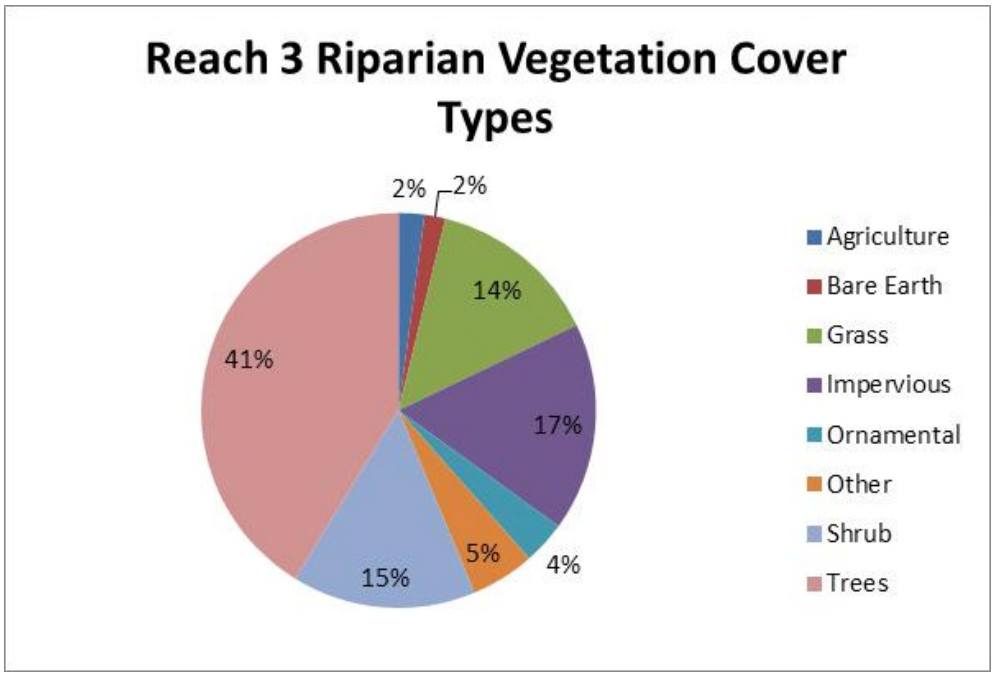



**Figure 4-23. Distribution of riparian vegetation cover types in Reach 3.**

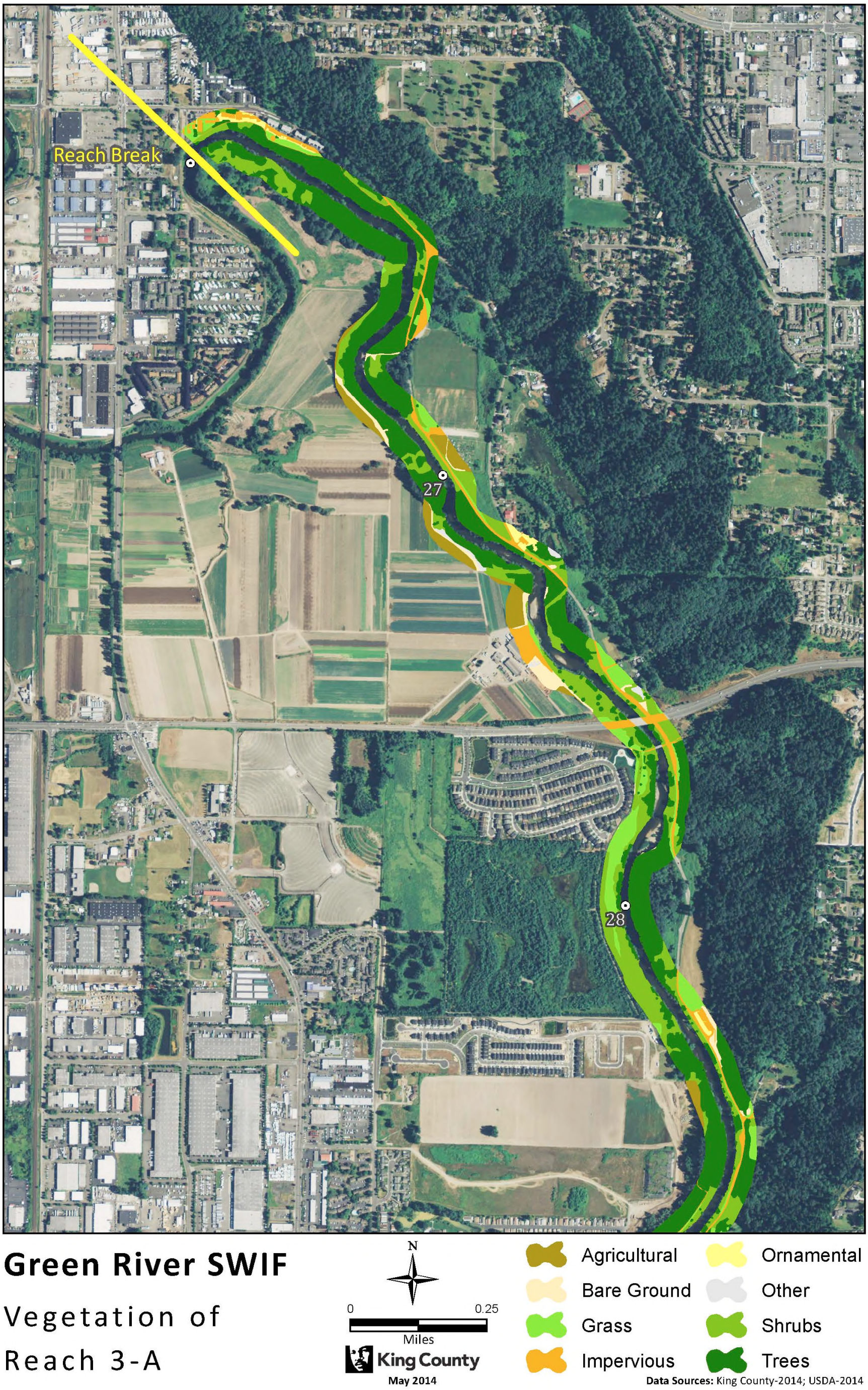



**Figure 4-24. Riparian vegetation types in downstream half of Reach 3 (3A).**

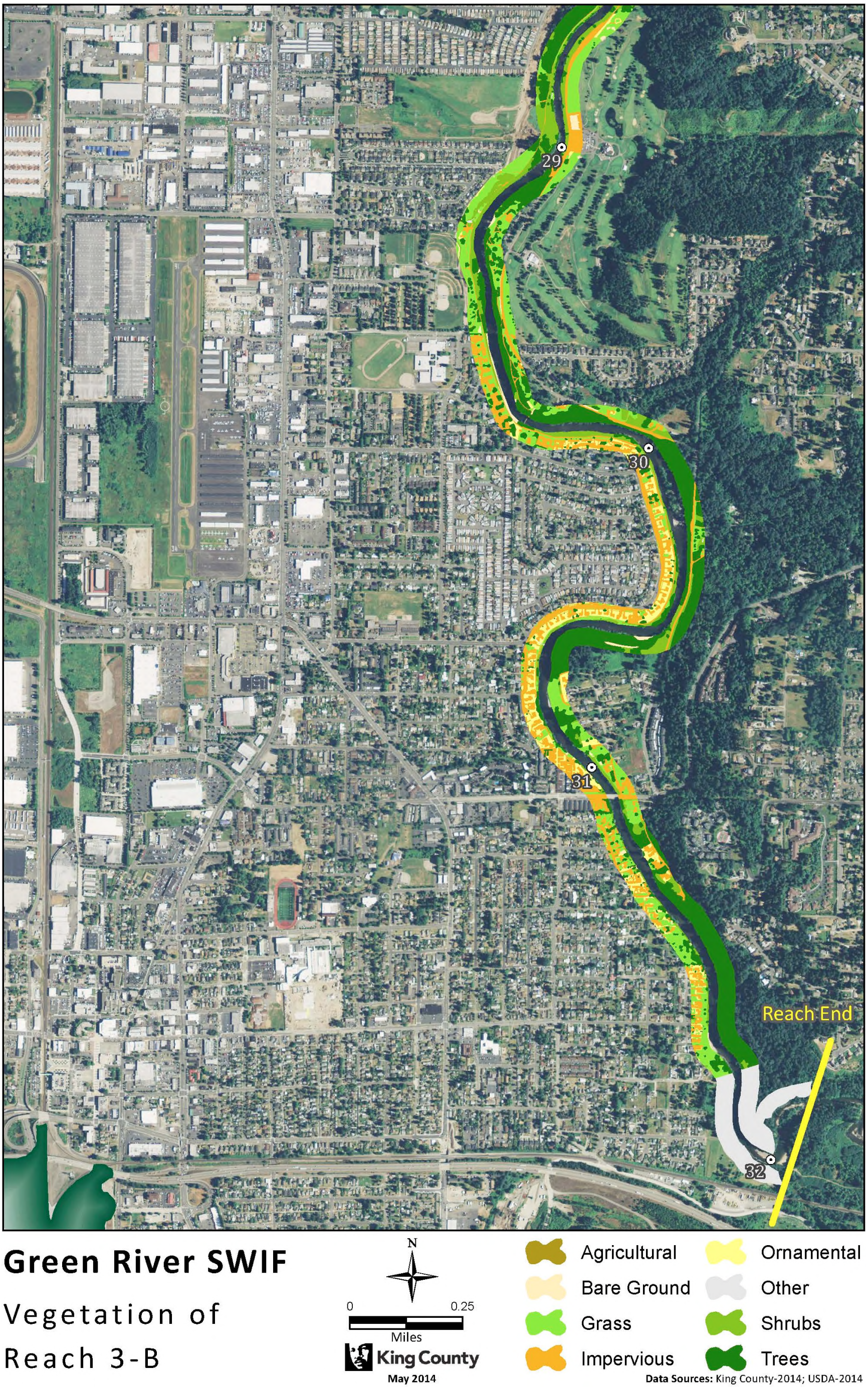
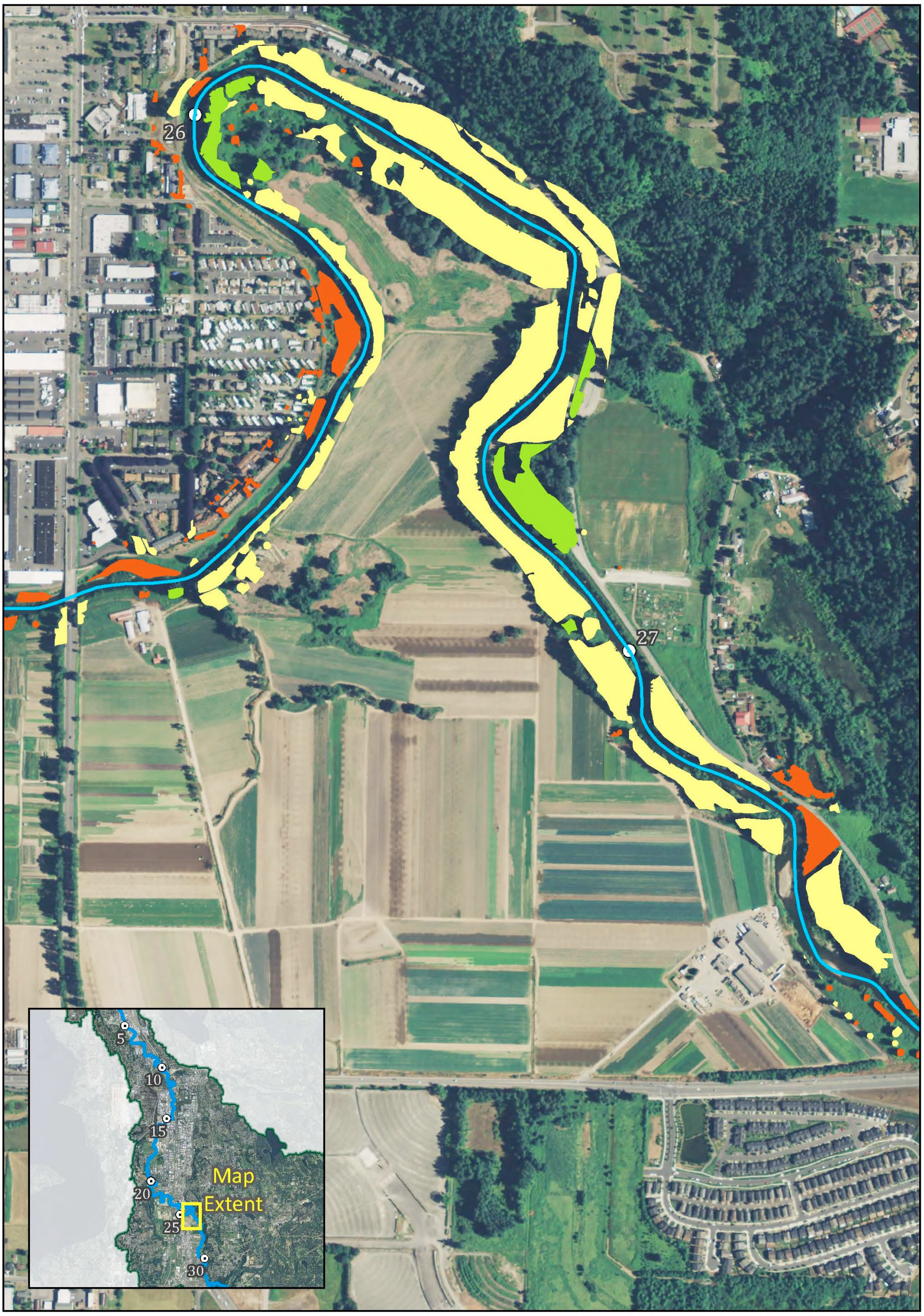



**Figure 4-25. Riparian vegetation types in upstream half of Reach 3 (3B).**




**Green River SWIF**

Vegetation Height:
River Mile 25.5
to Rive Mile 27.5

N

0 1,000
Feet

King County
May 2014

Less than 50 feet
50 to 100 feet
Greater than 100 feet
River Centerline

**Data Sources:** King County-2014; USDA-2011

**Figure 4-26. Tree height classes from RM 26-28.**

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### 4.1.5.3. Levee System #5, RM 28.6-30.79 (Left Bank)

Levee system #5 is comprised of three levee segments on the left bank of the river in Reach 3: 1) Brannon Park-Reddington levee from RM 28.6 to 29.18; 2) Galli's levee from RM 29.5 to 29.71; and 3) Dykstra levee from RM 29.71 to 30.79. This levee system primarily protects single family residential housing in the City of Auburn. Riparian vegetation cover types are shown for this levee system in Table 11 and Figures 4-27 and 4-28.In levee system #5, approximately 33% of land within the 200-foot riparian zone, totaling 17 acres is impervious surface – roads, parking lots, or buildings. Approximately 17% of the vegetation cover is grass and shrubs, each, and approximately 22% is trees.

The majority of levees have undergone recent repair (since 2008) and feature young shrub and planted trees. There is one large patch of trees on the lower end of the levee system that is approximately 3,500 feet in length, nearly 200 feet in width, with trees ranging from 50 to 100 feet high and some over 100 feet high. This is the best patch of trees in the PL84-99 levee systems. Other trees along levee system #5 are typically individual trees.

**Table 11. Vegetation cover types for Levee System #5.**

| Vegetation Cover Type | System 5 (acres) | Percent of Levee Area |
|---|---|---|
| Agriculture | - | |
| Bare Earth | 0.7 | 1% |
| Grass | 8.9 | 17% |
| Impervious | 17 | 33% |
| Ornamental | 5.2 | 10% |
| Other | 0.2 | 0% |
| Shrubs | 8.6 | 17% |
| Trees | 11.6 | 22% |
| **Totals** | **52.2** | **100%** |

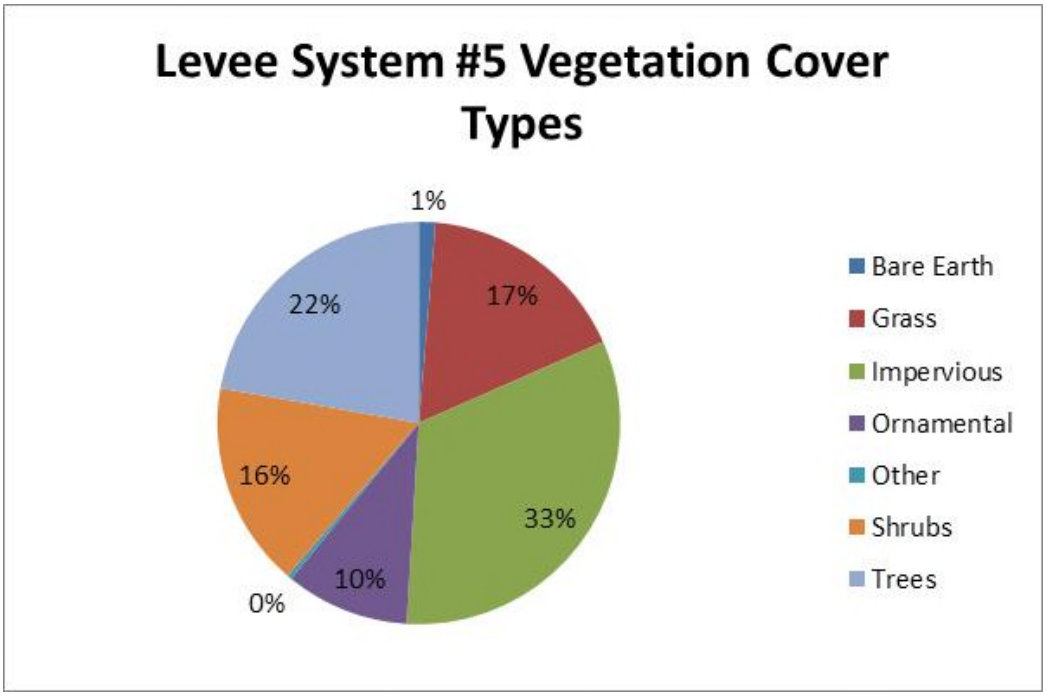


**Figure 4-27. Distribution of vegetation cover types for Levee System #5.**

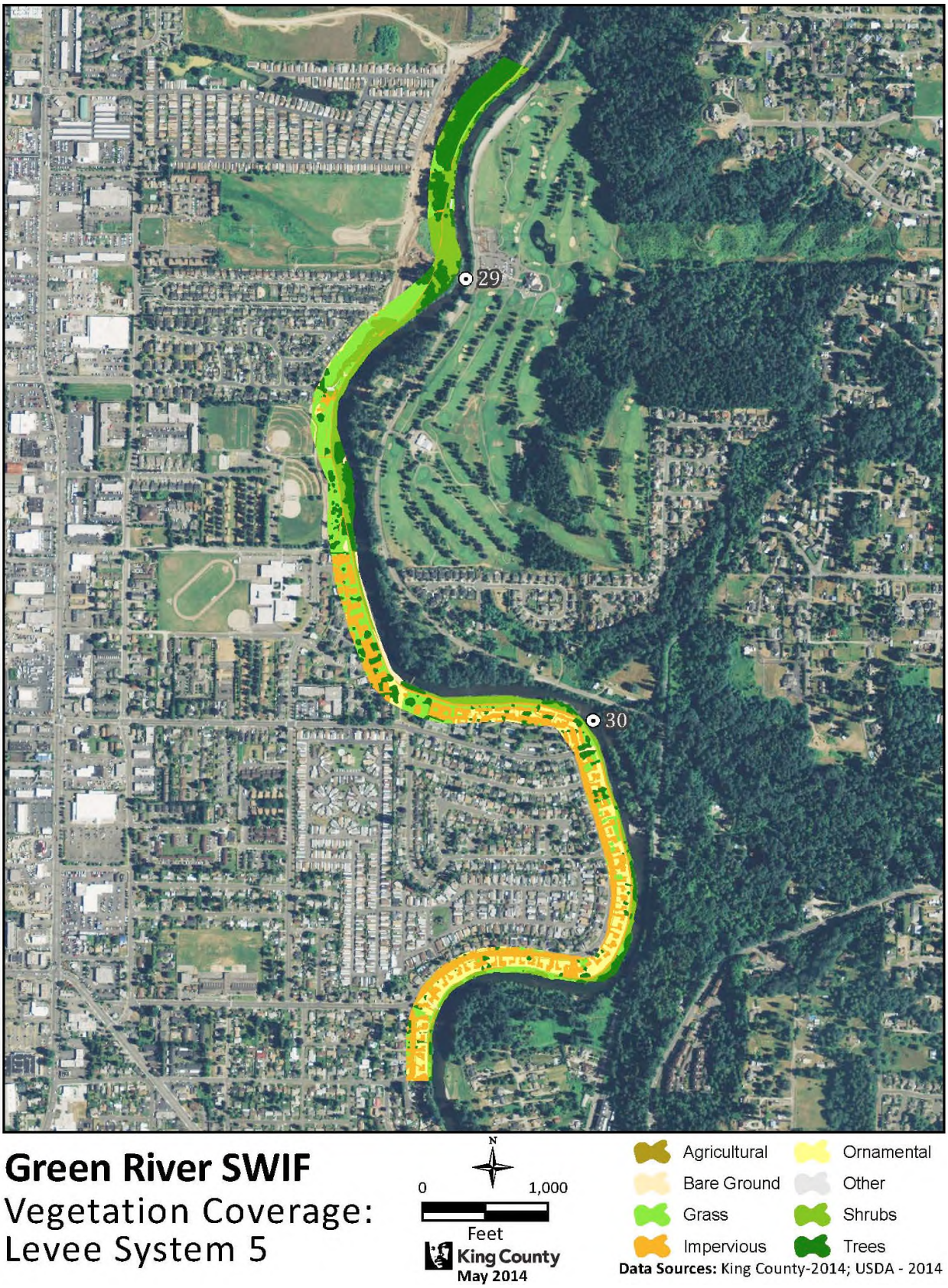


**Figure 4-28. Riparian vegetation polygons for Levee System #5.**

Table 12 shows how the riparian vegetation cover types compare between the PL84-99 levee systems and the rest of the Reach 3 riparian zone and the percentage that the PL84-99 levee occupies of Reach 3 for each cover type. The one PL84-99 levee system present comprises approximately 18% of the riparian zone in Reach 3. The grass, impervious, and ornamental cover types are more predominant in the PL84-99 levee system than in the reach as a whole, while the bare earth and tree cover types are less predominant in the levee systems than in the reach as a whole; shrub cover is fairly similar on the levee system as compared with the rest of the reach.

**Table 12. Riparian vegetation cover types on PL84-99 levees compared to Reach 2 as a whole.**

| Riparian Cover Type | Reach 3 (acres) | Percent of Reach 3 | PL84-99 Levees in Reach 3 (acres) | PL84-99 Percent of Reach 3 |
|---|---|---|---|---|
| Agriculture | 6.3 | 2% | -- | 0% |
| Bare Earth | 5.2 | 2% | 0.7 | 14% |
| Grass | 39.9 | 14% | 8.9 | 22% |
| Impervious | 48.8 | 17% | 17 | 35% |
| Ornamental | 10.9 | 4% | 5.2 | 48% |
| Other | 16 | 5% | 0.2 | 1% |
| Shrub | 44.4 | 15% | 8.6 | 19% |
| Trees | 121.2 | 41% | 11.6 | 10% |
| **Totals** | **292.7** | **100%** | **52.2** | **18%** |

A detailed comparison of PL84-99 levee system vegetation cover and native and non-invasive species is provided in Appendix C. Within Reaches 2 and 3, the PL84-99 levee systems represent approximately 40% of the riparian zone, non-PL84-99 levees/revetments represent approximately 25% of the riparian zone, and non-leveed or revetted areas represent the remaining 35% of the riparian zone. The PL84-99 levee systems are dominated by grass and impervious surfaces (Table 13 and Figure 4-29). The non-leveed or revetted areas are dominated by trees and shrubs, although impervious area is still high. Surprisingly, the other leveed and revetted areas have nearly equal dominance by trees, shrubs, grass, and impervious areas.

**Table 13. Riparian vegetation cover types comparison for leveed and non-leveed areas.**

| Riparian Cover Type | No Levees or Revetments (acres) | PL84-99 Levees (acres) | Other Levees (acres) | Revetments (acres) |
|---|---|---|---|---|
| Agriculture | 21.7 | 0.0 | 0.1 | 8.0 |
| Bare Earth | 8.4 | 21.7 | 0.5 | 6.7 |
| Grass | 43.1 | 96.7 | 12.5 | 43.9 |
| Impervious | 71.3 | 140.2 | 12.4 | 48.3 |
| Ornamental | 4.7 | 12.3 | 1.7 | 3.6 |
| Other | 15.6 | 1.4 | 0.0 | 1.1 |
| Shrub | 73.9 | 72.3 | 5.0 | 45.3 |
| Trees | 124.6 | 62.5 | 16.8 | 46.1 |
| **Totals** | **363.2** | **407.1** | **49.0** | **203.0** |

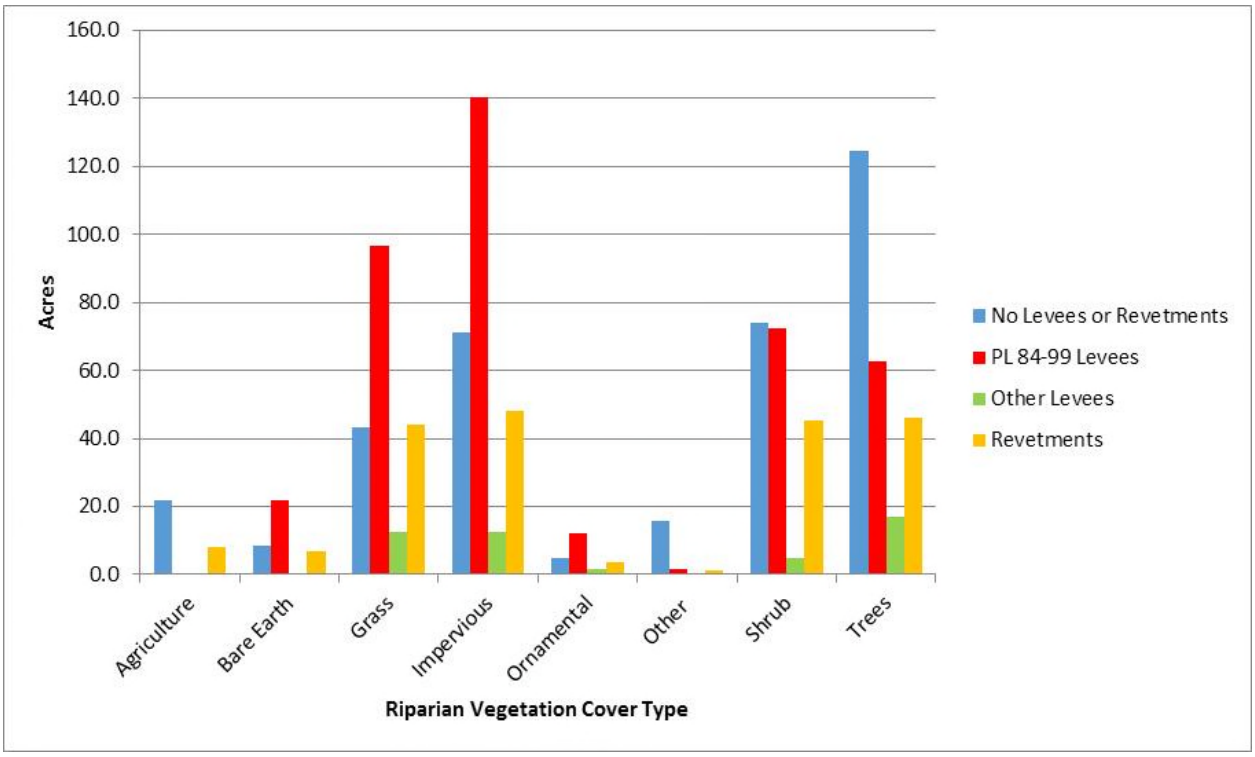


**Figure 4-29. Comparison of percent riparian vegetation cover for PL84-99 levee systems and non-levee system areas (Reaches 2 and 3 only).**

#### 4.1.5.4. Implications and Priorities

Providing forested riparian vegetation is a critical need to provide shade to the river, cover and overhanging vegetation over the aquatic habitat, and to contribute large wood over the long-term to the system. There is very limited tree cover in the majority of the Lower Green River and it is very important to restore riparian tree cover wherever possible to promote shading and cover. However, there are several good patches of trees, especially in Reach 3, so protecting the existing patches and then supplementing key gaps is an important consideration for developing SWIF alternatives.

### 4.1.6. Streamflow

Streamflows in the Lower Green River were highly altered following the diversion of the White River into the nearby Puyallup River in 1911. This diversion, which was stabilized and made permanent by construction of the Auburn Wall, is estimated to have reduced flows in the lower 15 miles of mainstem Green River channel by approximately 50% (Kerwin and Nelson 2000). The White River's glacial origin provided snow and ice melt well into the summer months, which had important effects on summer base flows and water temperatures in the Lower Green River. The volume of flow has a key effect on how much solar radiation can increase water temperatures; thus, higher flows in the river would be more likely to maintain cooler water temperatures. An estimate of the volume of flow required to meet water quality standards (17.5 C) was calculated by Massman (2013); during a warm year, over 2,500 cfs would be needed to maintain cooler temperatures and during a cooler year, over 1,300 cfs would be needed.

Flows were further modified in 1911 following construction of the Tacoma Diversion at RM 61, which reduced in-channel flows by about 113 cfs, or 12% of the average annual flow (King County and WRIA 9 2005). The flow characteristics of the Middle and Lower Green River were further altered after the

Howard Hanson Dam was completed in 1964. This major storage reservoir captures most high flow events and also traps wood and sediments (including spawning gravels) reducing supplies to downstream reaches of the Green River. Although the frequency of intermediate flow events has increased due to storage of peak flows in the reservoir, the truncation of higher flows has reduced channel-forming processes that are important for channel migration, sediment transport, and flushing of fines from spawning gravels. In addition to these flow-related effects, the lack of fish passage facilities at Howard Hanson Dam prevents migration of anadromous fish into the upper watershed.

A significant modification to Howard Hanson Dam was authorized in 1999 to support water supply and ecosystem restoration. The Howard Hanson Dam Additional Water Storage project (AWSP) was authorized in Section 101(b) (15) of the Water Resources Development Act of 1999 (Public Law 106-53, 17 August 1999). Phase 1 of the AWSP provides an additional 20,000 acre-feet (ac-ft) for water supply for Tacoma and raises the conservation pool to an elevation of 1167.0 feet. The current authorization also provides features for ecosystem restoration and compliance with ESA, such as the construction of a new fish passage facility and various habitat improvement sites upstream and downstream of the dam. The non-water supply components of the project are intended to promote the reestablishment of self-sustaining runs of ESA-listed salmon in the watershed above Howard Hanson Dam for the first time since 1912. Tacoma has constructed a fish passage/collection facility at the Tacoma Diversion. Water was first stored to an elevation of 1167.0 feet for municipal and industrial water supply purposes in 2007. The elevation 1167.0 pool has been maintained during each conservation season through 2013.

Under the current authorization, Phase 2 of the AWSP would store an additional 12,000 acre-feet of water and is divided into 2,400 acre-feet for water supply and 9,600 acre-feet for low-flow augmentation. Phase 2 would raise the pool elevation to 1177.0 feet in the spring for release in the summer and fall. Phase 2 cannot be completed until the Phase 1 water supply implementation is completed. Phase 2 water supply includes habitat construction projects that are required to mitigate the project effects. Construction of Phase 2 could be several years in the future.

Completion of Phases 1 and 2 is dependent on reauthorization of the project because the current estimated costs exceed the amount authorized. The downstream fish passage facility at Howard Hanson Dam has not been completed due to the high costs of the original design and currently does not have a completed design for an alternate facility.

#### 4.1.6.1. Implications and Priorities

The Green River SWIF cannot have a substantial effect on streamflows in the basin; although higher flows would help to maintain cooler water temperatures as it takes more solar radiation energy to heat up larger volumes of water. However, providing floodplain connections can help to reduce velocities and provide off-channel refugia during moderate-high flow releases from Howard Hanson Dam. Providing fish passage into the upper basin is also a critical need to ensure there is sufficient spawning habitat in the overall watershed to support sustainable salmonid populations.

### 4.1.7. Groundwater

Groundwater can be an important source of flow into the river during low flow periods. King County and WRIA 9 (2005) cite two studies of groundwater (Pacific Groundwater Group 1999 and Brown and Caldwell 1989) that identified substantial groundwater flow into the Green River along the former White River channel (RM 31-32) and in the Middle Green River (RM 48 to 52) where numerous springs discharge to the river. The porous nature of the soils along the former White River channel (NRCS 2014) such as Everett gravelly sandy loam would allow groundwater flows. It would be important to maintain

good shading conditions near and downstream of important groundwater flow inputs to maintain cool water temperatures for as long as possible downstream.

The positive effect of minimizing runoff and infiltrating water into the ground to increase base flows is well documented. Maintaining or enhancing groundwater recharge through local and regional land use practices and infiltration of stormwater/reclaimed water in some places may help provide temperature benefits in a shorter timeframe than riparian shading. In addition, enhancing groundwater recharge may mitigate the effects of inadequate shade where it is not possible to provide substantial tree cover.

#### 4.1.7.1. Implications and Priorities

Protecting the existing groundwater flow from the White River is a key priority. More information on the location, quality, and volume of flow is very important to understand how to protect this flow, as it appears most of the former White River channel pathway has already been developed, but this flow still exists. Then, providing floodplain connections for potential groundwater recharge is a second critical priority. This will be small in scale, but may contribute groundwater discharge during base flows. Setting back levees and allowing more gravel bars in the river can also increase the exchange of hyporheic flow. While these actions are not likely to reduce daily average temperatures, it could reduce the larger variability of maximum highs and low temperatures.

# 5. WATER QUALITY

## 5.1. WATER TEMPERATURE

The Green River watershed has undergone extensive habitat alterations over the past 150 years. Historically, streamside tree cover along the Lower and Middle Green River included red alder, black cottonwood, big leaf maple, vine maple, red alder, and willow (Coffin et al. 2011). Riparian habitat plays a valuable role in protecting stream water quality and moderating the negative impacts occurring in a stream basin. Adequately-sized and healthy riparian buffers help filter out fine sediment and other pollutants, provide shade to moderate stream temperatures, provide overhead cover to aquatic species, and provide a source of LWD for the proper biologic and hydraulic functioning of a healthy watershed.

The Washington Department of Ecology (WDOE) water temperature standard is 63.5° F (17.5° C) for salmonid spawning, rearing and migration (September 16 to June 14) and 60.8° f (16° C) for core salmonid summer habitat (June 15 to September 15; WDOE 2012). This is similar to Environmental Protection Agency (EPA) guidance that recommends daily maximum temperatures not exceed 64° F (18° C; USEPA 2003) in waters where adult salmon migration and non-core juvenile rearing occurs. A review of temperature requirements and effects on salmonids by Carter (2005) indicates that 50 percent mortality of Chinook occurs around 77° (25° C), but coho are more tolerant and 50 percent mortality occurs at 82° F (28° C). NOAA (1996) considers optimal temperatures for salmonids to be 50-57° F (10-14° C). Beyond acute mortality, high water temperatures cause a variety of physiological effects (sub lethal) that are harmful to salmon survival and reproduction as well as increasing the potential for disease. Disease risk becomes high at temperatures from 64-68° F (18-20° C; USEPA 2003).

The federal Clean Water Act (CWA) requires that a total maximum daily load (TMDL) be developed for each of the water bodies on the 303(d) list. The 303(d) list is a list of “impaired” water bodies, which do not meet state water quality standards. The Middle and Lower Green River segments have both been identified as temperature impaired water bodies. The Green River water temperature TMDL (Coffin et al. 2011) is intended to help focus efforts to protect and enhance cold water habitat for resident and anadromous salmonids.

In the TMDL analysis (Coffin et al. 2011), stream temperature data from field monitoring supported the development of QUAL2Kw, a water quality model, which was used to describe existing conditions and compare how different hypothetical meteorological, shade, and flow conditions would affect the temperature along 54 miles of the Middle and Lower Green River below Howard Hanson Dam. In particular, scenarios of riparian shading along the river were considered. Water temperatures vary diurnally in response to changes in weather conditions and river flows. Since the maximum temperatures most dramatically affect aquatic species, the criteria evaluated in the TMDL analysis are expressed as the highest seven-day average of the daily maximum temperatures (7-DADMax) occurring in a water body.

The beneficial uses to be protected and the corresponding thresholds that were evaluated in the TMDL analysis included:

1. Core Summer Salmonid Habitat - protects summer season (June 15 through September 15) salmonid spawning, incubation, emergence, and adult holding; summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char. To protect these designated

aquatic life uses, the highest 7-DADMax temperature must not exceed 16°C (60.8°F) at a probability frequency of more than once every ten years on average; and .

2. Salmonid Spawning, Rearing, and Migration - protects salmonid spawning, incubation, and emergence that may occur outside of the summer season (September 16 – June 14) and protects rearing and migration during this period. To protect theses designated aquatic life uses, the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) at a probability frequency of more than once every ten years on average.

The 16°C criterion applies to the Green River upstream of the Mill Creek confluence at about RM 24; downstream of Mill Creek the 17.5°C criterion applies.

The TMDL analysis used effective shade as a surrogate measure of heat flux from solar radiation. Effective shade is defined as the fraction of potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Monitoring indicated that a shade deficit occurred throughout the Middle and Lower Green River, but was especially prevalent below the city of Auburn (below RM 26) due to the extensive channelization and levee construction. Continuous temperature data were recorded throughout the summer of 2006. All thirteen of the stations monitored by WDOE on the Green River mainstem exceeded the seven-day average temperature standard (Table 2). Modeling and data analysis determined that portions of the Green River failed to consistently meet state water quality standards and provide unsuitable and sometimes lethal temperatures for salmonids that use these waters for migration, spawning and rearing.

The TMDL model demonstrated that temperatures in the lower reaches of the Green River approach and sometimes exceed lethal conditions for salmonids during the critical summer/fall months. Lowering water temperatures will help to reduce salmonid mortality and improve habitat and provide a means of restoring and improving the basin's salmon production. The model used in the Green River temperature TMDL analysis shows that under current conditions daily maximum water temperatures in excess of the 16°C water quality standard occur along the entire Middle and Lower Green River basin (Table 14). The 17.5 °C standard below Mill Creek protecting salmonid spawning, rearing, and migration is also exceeded. The lower 8 miles of the river are also predicted to exceed the 22°C threshold for lethality under existing conditions during high summer temperatures and low flow conditions.

**Table 14. Highest 7-day of daily maximum temperature recorded in the Green River during the summer 2006 (from Coffin et al. 2011).**

| Station ID | Location | Temperature (°C) | |
|---|---|---|---|
| | | Highest 7-DADMAX | WQ Standard |
| **Middle Green River** | | | |
| 09-GRE-DAM | Below Tacoma Headworks Dam | 17.76 | 16.0 |
| 09-GRE-KAN | At Cumberland-Kanaskat Rd. | 19.22 | |
| 09-GRE-FLA | At Flaming Geyser Park | 19.74 | |
| 09-GRE-WHI | At Whitney Bridge | 21.83 | |
| 09-GRE-GRE | At Green Valley Road | 21.58 | |
| **Lower Green River** | | | |
| 09-GRE-8TH | At 8th St. NE, Auburn | 20.98 | 16.0 |
| 09-GRE-277 | 277th St. Bridge | 20.94 | |
| 09-GRE-167 | Highway 167 Bridge | 21.42 | |
| 09-GRE-OLD | Meeker St. near "Old Fishin' Hole" | 21.59 | |
| 09-GRE-212 | At S. 212th St. | 22.16 | |
| 09-GRE-180 | At SE 180th St. (SW 43rd St.) | 22.61 | |
| 09-GRE-FOR | Interurban Ave. Bridge near Fort Dent | 22.84 | |
| 09-GRE-COM | 42nd Ave S. Bridge at Tukwila Community Center | 23.14 | |

The model shows that even with comprehensive and wide potential riparian planting scenarios, the water temperature are still predicted to exceed the 16° criterion by 2 to 3 degrees. Current conditions within these reaches exceed the criterion by approximately 5.5 degrees. The 17.5° criterion below the confluence with Mill Creek is nearly achievable when using 32 m tree height as a modeling parameter to create a system potential shade scenario. If taller and broader 42 m tree height is used, compliance with the 17.5° criterion can potentially be met.

Under all scenarios the maximum water temperatures remain below lethal limits for salmonids upstream of Mill Creek, but would still likely have sublethal effects. Even when all riparian areas along the middle and lower basin, except the levees, are vegetated with full site potential shade, lethal temperatures will still occur from approximately RM 11-14 of the Green River. Until the federal levee vegetation maintenance policy can be changed to allow for growth of large trees on these structures, or the levees are set back to allow for planting, or the County removes levee facilities from PL84-99 program, or some other mitigation technique can be implemented, temperatures are not likely to meet the identified standards in the lower Green River and will reach lethal temperatures in warmer years.

The TMDL study evaluated approaches to reducing temperature in the middle and lower reaches of the river, which will in turn improve dissolved oxygen, establishment of mature full riparian vegetation for shade, and microclimate. The TMDL models show that the combined effects of mature riparian vegetation along the entire riparian corridor and the associated microclimate improvements result in the greatest temperature improvements in the river. It should be noted that such recommendations are long term solutions that will require decades to implement and achieve. Regardless, planting or restoring riparian vegetation of any buffer size that is deemed feasible can still provide value and is encouraged.

Also, the TMDL model shows that decreasing the temperatures and increasing the flows in the tributaries helps to maintain lower temperatures in the mainstem. In order to protect and enhance the salmonid resources of the Green River Basin, the tributaries must also supply an adequate flow of cool clean water. The main tributaries in the Middle and Lower Green River are Mullen Slough, Mill Creek,

Soos Creek, and Newaukum Creek. Newaukum Creek also has a recently completed temperature TMDL. Individual water temperature and dissolved oxygen TMDL's are currently being prepared for Soos Creek, which WDOE will document in separate reports.

## 5.2. SHADE MODELING

### 5.2.1. MUCKLESHOOT TRIBE SUN MODEL

The Muckleshoot Indian Tribe (Fox Draft 2013) prepared a sun exposure model to identify and map critical areas for providing forested riparian zone to maximize the potential shading of the Lower Green River from RM 15 to 34. This simple tool calculates the aspect of the river oriented to North, South, East, West coordinates – areas with more southerly exposure are considered critical for shading. Figures 5-1 through 5-4 show the results from the sun model that identifies priority areas where it is most critical to provide forested riparian zone and shade. It is important to note that this simple tool does not account for differing bank topography, or combined effects of both banks being vegetated and is simply based on the orientation of each bank of the river.

Notable locations identified as critically important for shade in Reach 2 include RM 14 to 14.5, RM 15 to 15.5, RM 16 to 18, RM 18.4 to 19.5, RM 20.8 to 21.3, RM 22 to 23., and the majority of the left bank from RM 23 to 26. Notable locations identified as critically important for shade in Reach 3 include the majority of the left bank from RM 26 to 29, RM 29.2 to 29.8, RM 30 to 30.5, and the majority of the left bank from RM 30.7 to 33. The locations where the sun model coincides with poor conditions for the existing riparian vegetation and shading are predominantly at RM 27.4 to 27.7, RM 29.8 to 30 and RM 30 to 30.2.

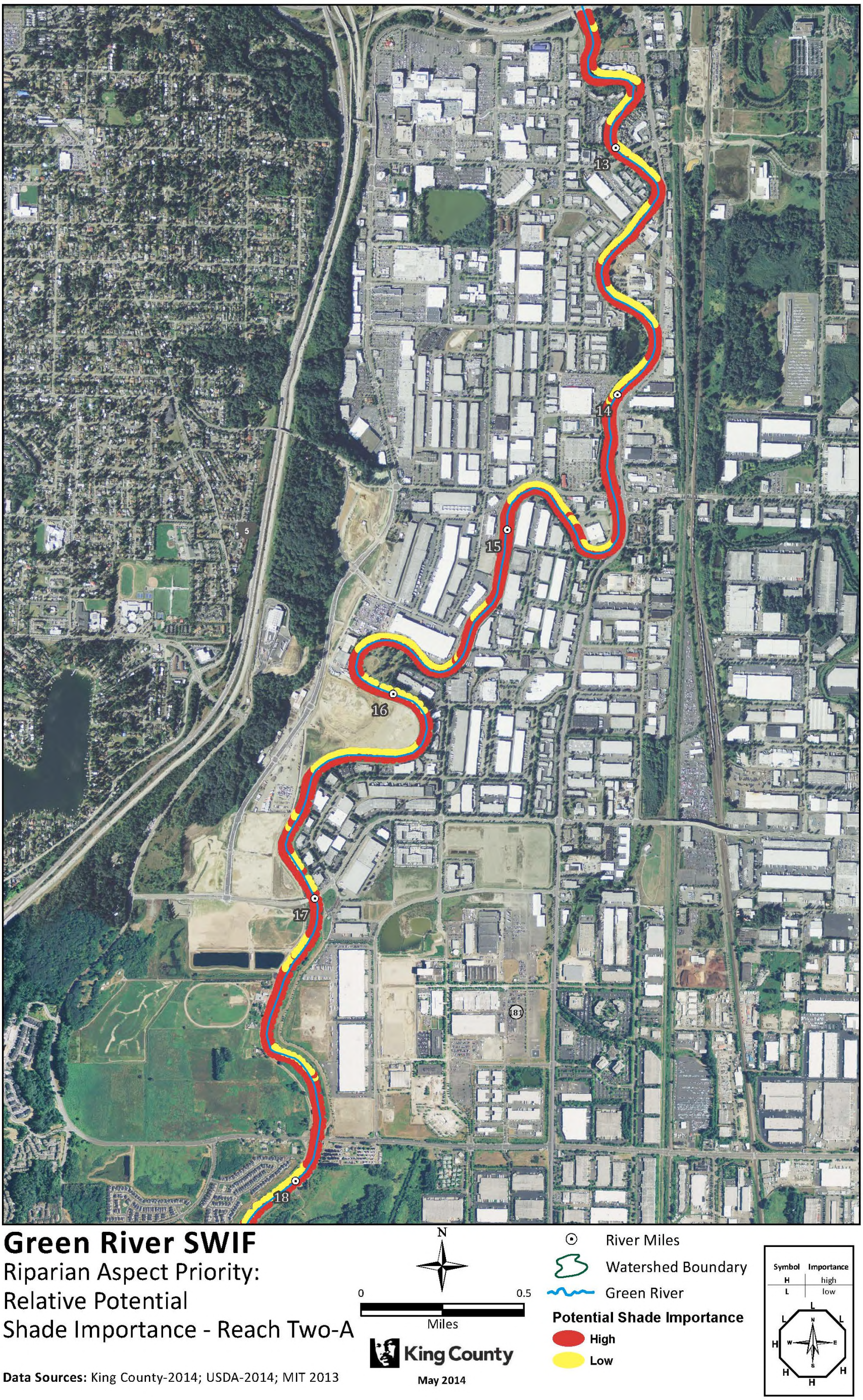


Figure 5-1. Sun model critical shade needs for downstream half of Reach 2 (2A).

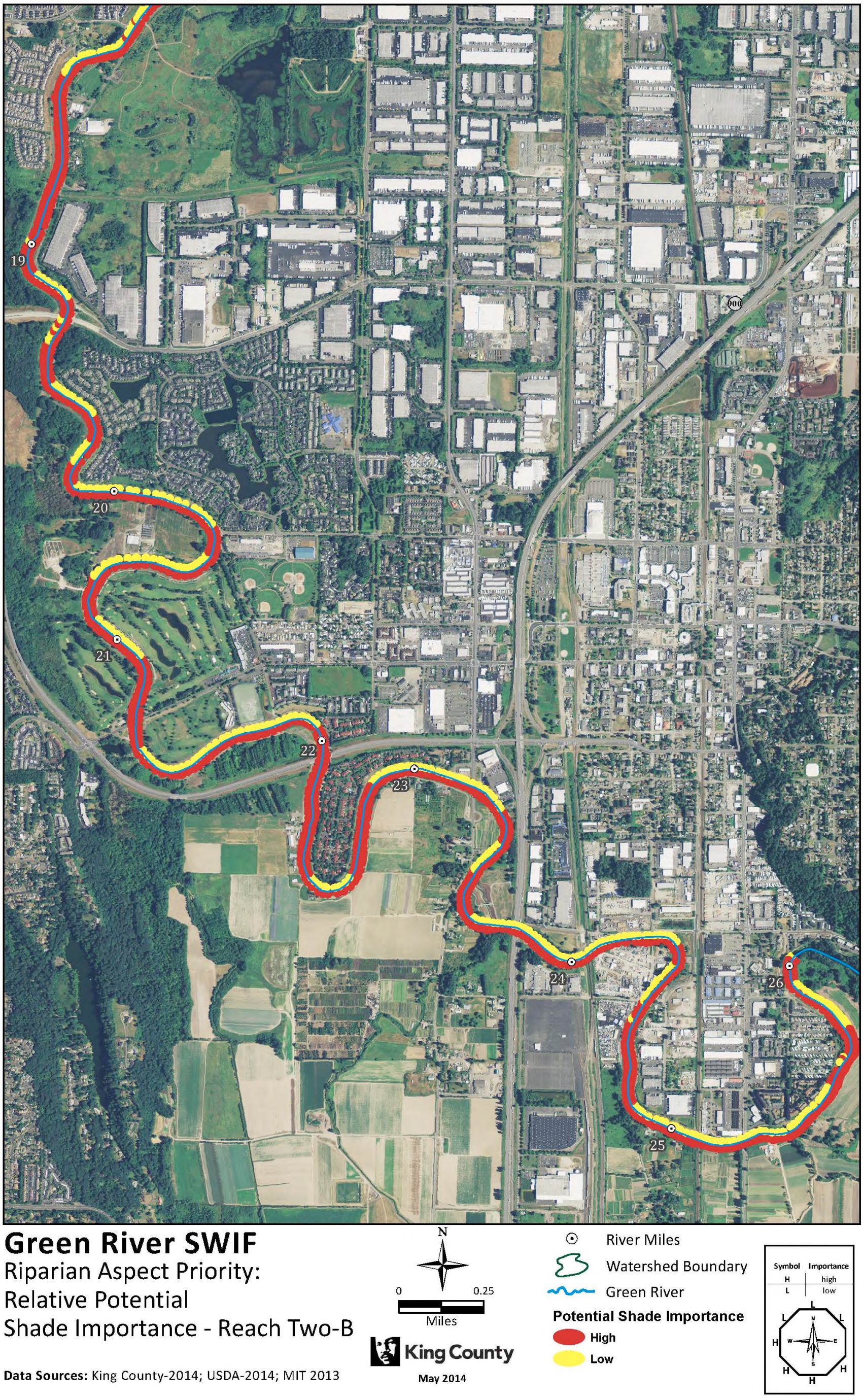


**Figure 5-2. Sun model critical shade needs for upstream half of Reach 2 (2B).**

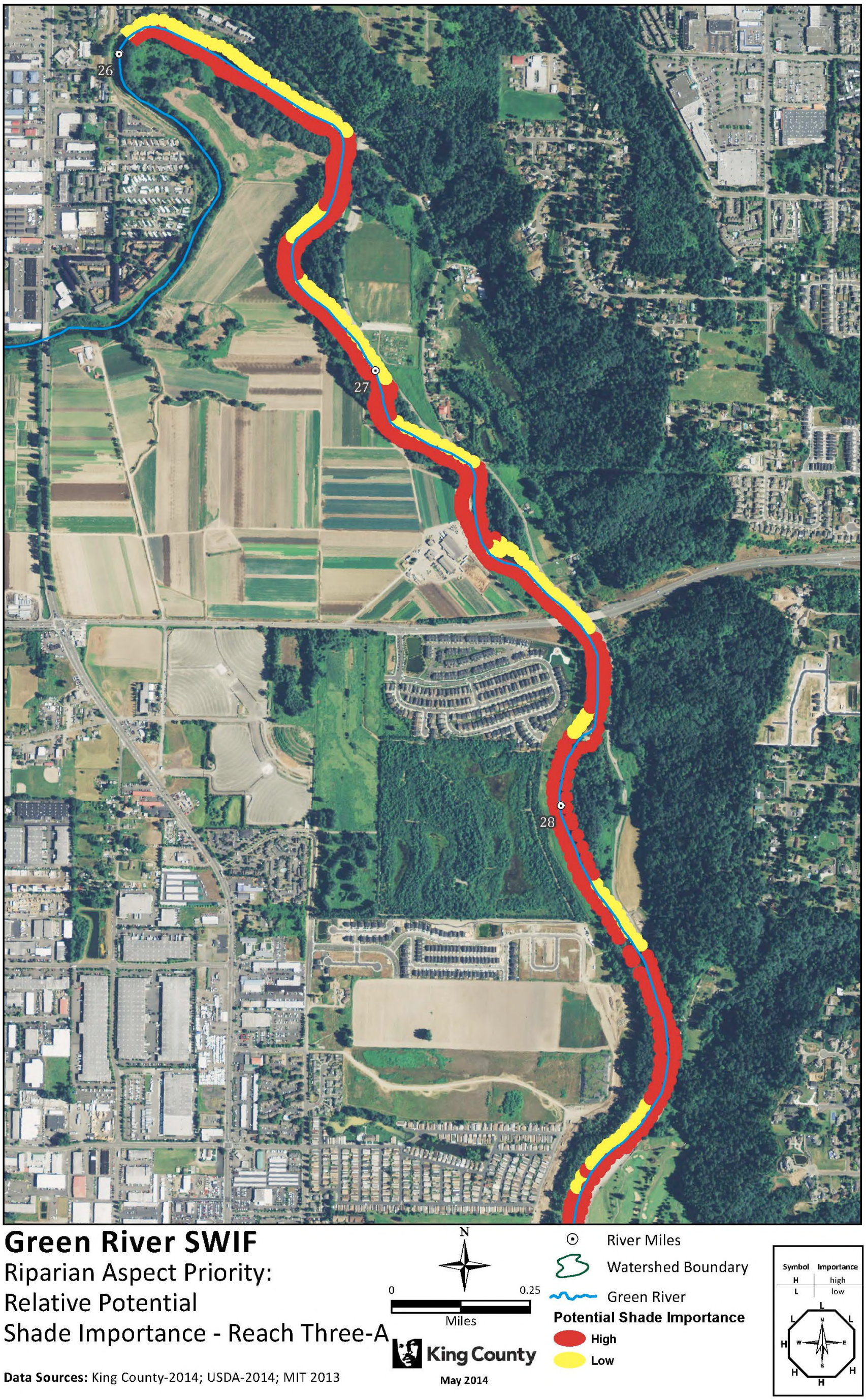


**Figure 5-3. Sun model critical shade needs for downstream half of Reach 3 (3A).**

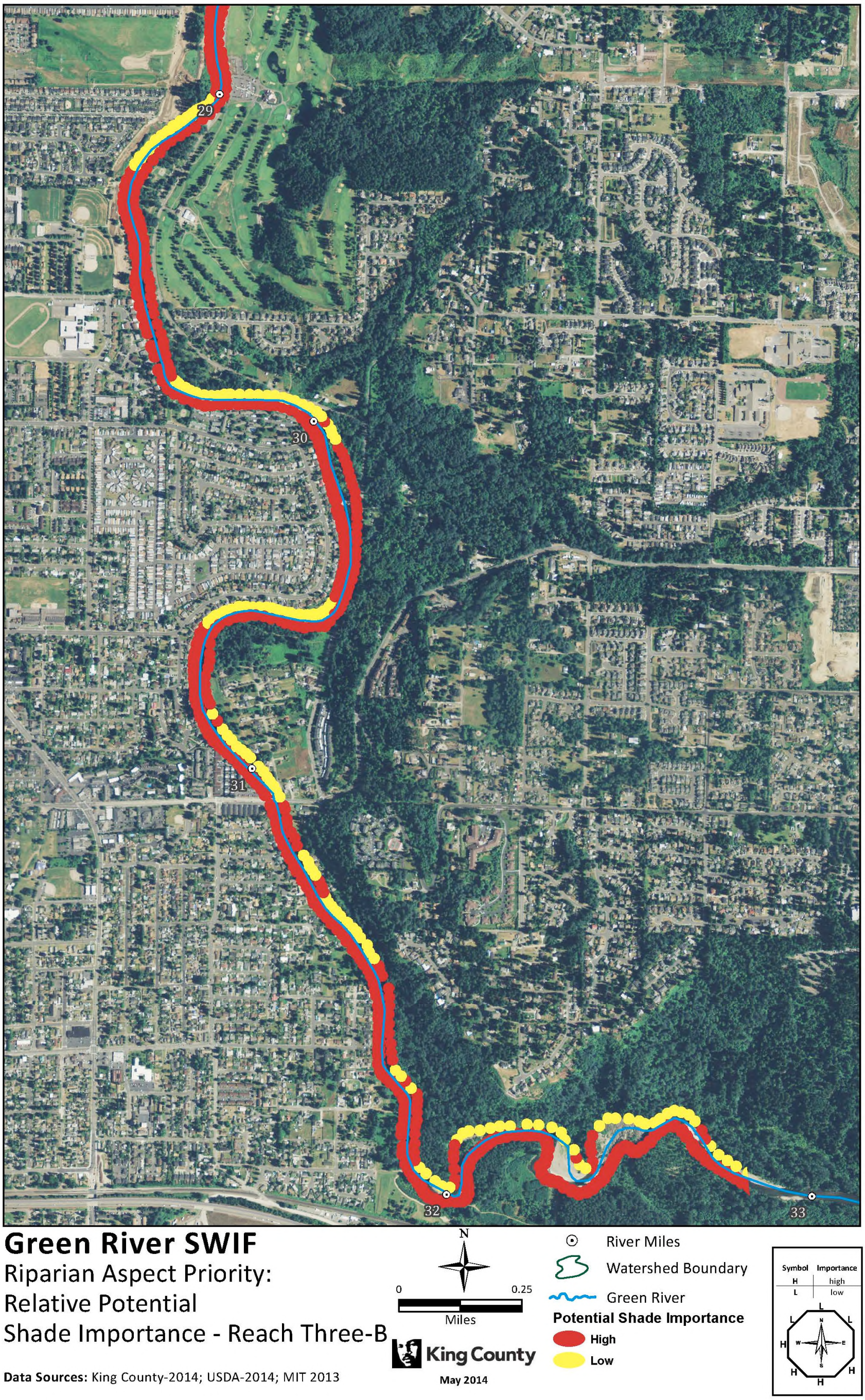


Figure 5-4. Sun model critical shade needs for upstream half of Reach 3 (3B).

### 5.2.2. POTENTIAL SHADE GIS MODEL OVERVIEW

Elevated water temperatures are a chronic problem in the Lower Green River. To better understand potential shade provided by riparian trees along both banks of the river, the project team and advisors built upon the concepts developed by the Muckleshoot Tribe's sun model (Fox Draft 2013) relative to orientation of the river and angle of the sun and developed a GIS model that analyzes the potential shade cast by existing trees during daylight hours (on August 1st) within an 150-foot riparian zone. The raster GIS model and its underlying code reflect TMDL work for the Green River, completed in 2011 (see preceding section for additional detail). Model output summarizes the potential for various vegetation scenarios to shade the river and assigns a categorical value of: Poor, Fair, Good or Very Good to potential shade conditions.

This shade modeling tool can also be used to support the evaluation of proposed changes to riparian vegetation (i.e. planting of additional trees, removal of trees, etc.) and the anticipated effects to potential shade provided to the river.

An overview of Potential Shade GIS model:

1. The right bank and left bank of the Lower Green River were each assigned 150-foot wide riparian buffer zones. Each 150-foot riparian buffer was further split into six equal 25-foot wide buffer increments. Riparian vegetation height is set at 32 meters (105 feet) to be consistent with the TMDL (Coffin et al. 2011).
2. 2013 high hit return LIDAR data was clipped to each 25-foot buffer increment, within the 150-foot zone.
3. The model is structured to run using the sun elevation and azimuth on August 1st, from the first hour after sunrise to the last hour before sunset, 7:30AM to 8:30PM. (14 hours in total).
4. Solar Radiation values were generated for each of the 14 hours on August 1st 2014, representing clear sky radiation above the Lower Green River before interception by vegetation (provided by Washington State's Department of Ecology Solar Radiation model – solrad_ver16.xls)
5. For each hour, the ESRI Hillshade tool was used to model shadows cast by each 25 foot buffer, right and left bank, on each grid cell representing the surface of the river.
6. During each hour the cumulative reduction in incoming solar radiation was calculated for each river grid cell by reducing the radiation by 50 percent each time a buffer casts a shadow on the cell (50% reduction based on published canopy density-buffer width relationship).
7. The sum of the radiation reaching each river grid cell was divided by the total incoming (above tree canopy) solar radiation over the course of the day to generate a shade value for each 3-foot rasterized grid cell (1 minus this number is the potential shade or the amount of solar radiation blocked by riparian vegetation).
8. Each grid cell's shade value was presented as a function of its shade potential and categorized as Poor, Fair, Good or Very Good. The categories are based on the evaluation of the system potential shading with 105 foot-tall vegetation used as the primary analysis scenario in the TMDL) where the Lower Green River maximum effective shade is approximately 70%.

Results of the modeling are available for Reaches 2 and 3 of the Lower Green River and shading on the river is categorized as poor, fair, good, or very good (Table 15 and Figures 5-5 through 5-8). The categories are based on increments of the system potential shading (105 feet [32 meter] tall trees as modeled in the TMDL; Coffin et al. 2011) where the Lower Green River maximum effective shade is

approximately 70%. The Lower Green River is sufficiently wide that even trees over 100 feet in height on both banks cannot shade the river entirely; and, as the sun moves across the horizon, the sun can shine directly down on the river during the middle of the day. The GIS-based shade model has results for shading that range from 0 to 1 (index values); the categories of poor, fair, good, or very good are equal increments from the minimum to maximum values of shade that result from the GIS analysis.

Reach 2 has very poor shade conditions with the vast majority (63%) of the reach in poor conditions or fair conditions (33%). Less than 5% of Reach 2 has good or very good condition. The only small patches of good conditions are located at RMs 13.2, 13.8 in PL84-99 levee system #1, and RM 23.6 and along the left bank edge around Horseshoe Bend, in the Agricultural Production District. These locations are all associated with patches of trees on the left bank. Fair conditions are present adjacent to the treed hill slope near RM 11.6 and 12.5, adjacent to a tree patch from RM 13.6-13.8, at RM 17.8-17.9, the forested patch from RM 19-19.5, at the golf course from RM 20.9 to 21.5, from RM 22 to 23, RM 23.5-23.6, RM 24.2 to 25, and from RM 25.4 to 25.8.

Reach 3 has the majority of area with fair (56%) or good (24%) shade conditions, but also nearly 20% of the reach has poor shade conditions, both along the PL84-99 levee system #5 and other areas. Less than 1% is in very good condition. Notable patches with good conditions occur at RM 26 to 26.5 in North Green River Park, at RM 28.5, near RM 29, RM 30.5, 31.5, and 31.8. Notable poor condition areas are at RM 27.4 to 27.6, RM 29.1, 29.8 to 30.1, and 30.5-30.6.

**Table 15. Existing shade conditions in study area.**

| Shade Category | Index Range | Percent of Maximum | Actual Percent Effective Shade | River Area Reach 2 (Acres) | Percent Area (Reach 2) | River Area Reach 3 (Acres) | Percent Area (Reach 3) |
|---|---|---|---|---|---|---|---|
| **Very Good** | 0.81-1.0 | 80-100% | 61-75% | 0.1 | <1% | 1.2 | <1% |
| **Good** | 0.61-0.8 | 61-80% | 46-60% | 6.5 | 4% | 22.9 | 24% |
| **Fair** | 0.41-0.6 | 41-60% | 31-45% | 52.6 | 33% | 52.3 | 56% |
| **Poor** | 0.2-0.4 | 20-40% | 15-30% | 98.7 | 63% | 17.7 | 19% |
| **Totals Per Reach:** | | | | **157.9** | **100%** | **94.1** | **100%** |

The locations where the results from the sun model coincide with poor conditions for the existing riparian vegetation and shading are predominantly at RM 14 to 15, RM 16 to 17, RM 19.6, RM 21.5 to 22, RM 22.5, RM 23.5 to 24.3, and RM 25. The sun model predicts that more southerly aspects (i.e. south bank of the river) are the highest priority, and the shade model appears to bear this out that even a single line of trees along a south bank can cast a shadow sufficient to create fair to good conditions in the vicinity of the bank – and an even wider or taller riparian zone would likely cast a larger shadow. Although more northerly aspects (i.e. the north bank of the river) were rated as lower priority in the sun model, there are many instances where the shade model indicates that a western exposure (unvegetated) may have a critical influence on the lack of shade even on north banks, so understanding where western bank exposure is a critical priority is also important.

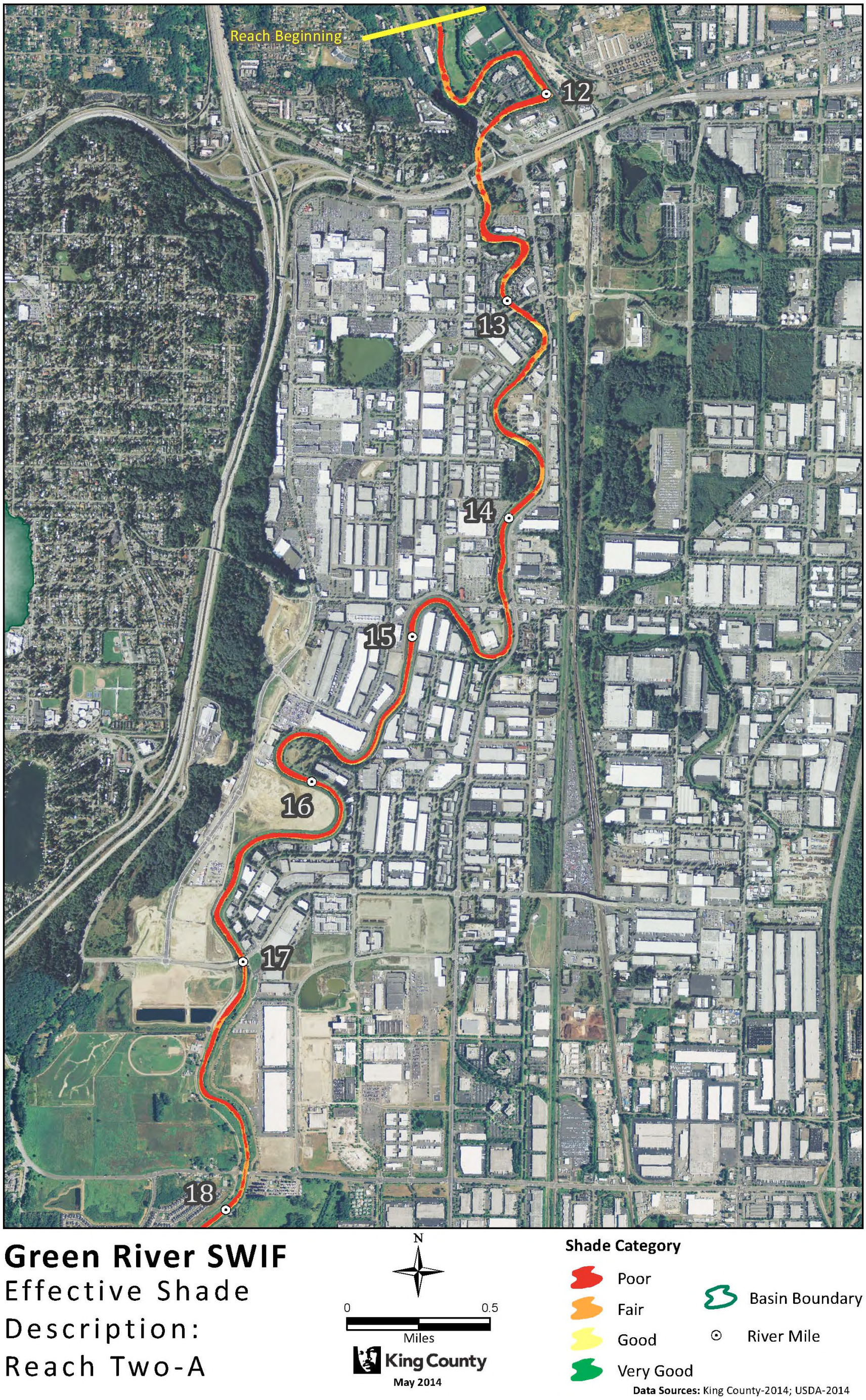


**Figure 5-5. Current effective shade conditions in downstream half of Reach 2 (2A).**

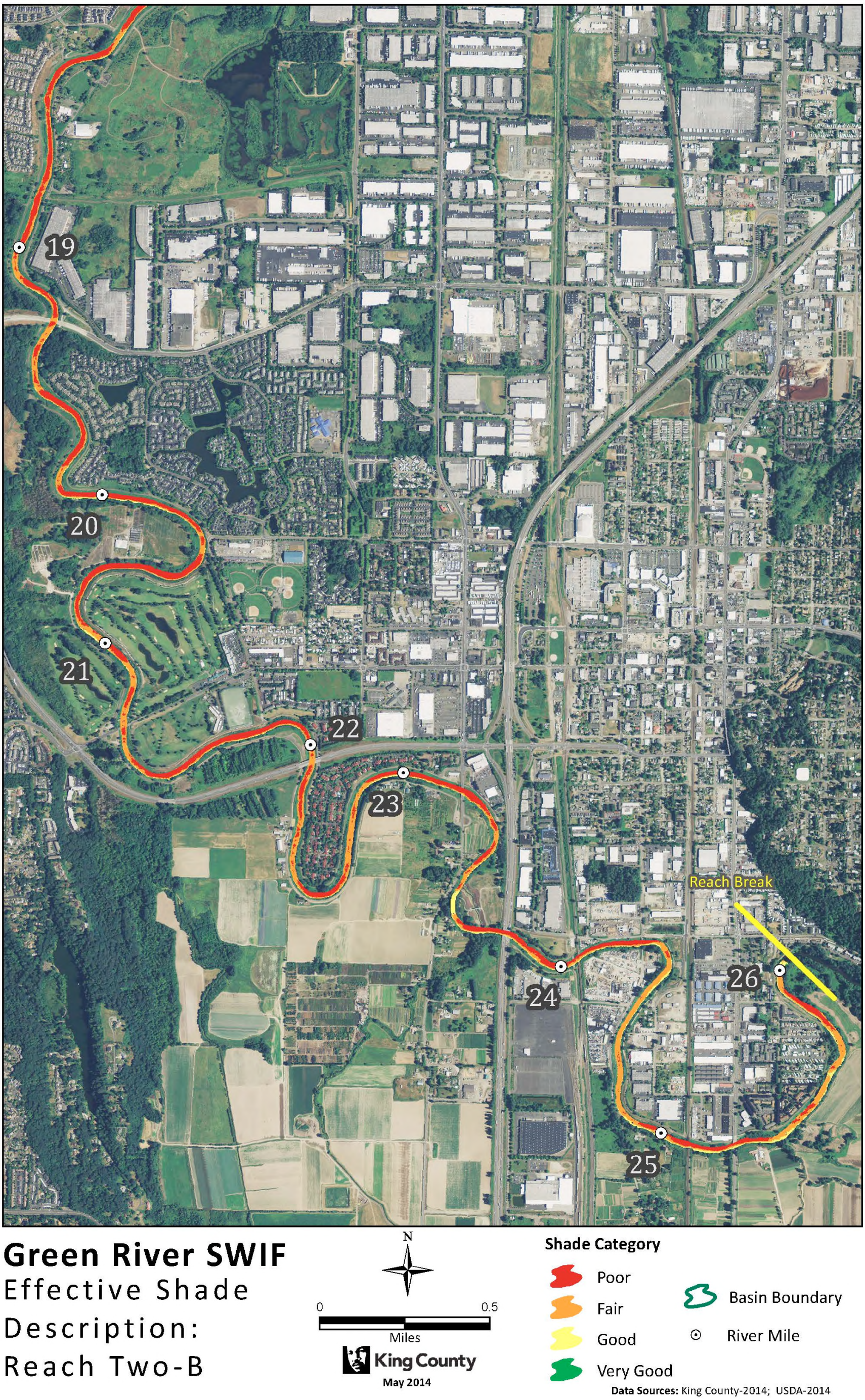


**Figure 5-6. Current effective shade conditions in the upstream half of Reach 2 (2B).**

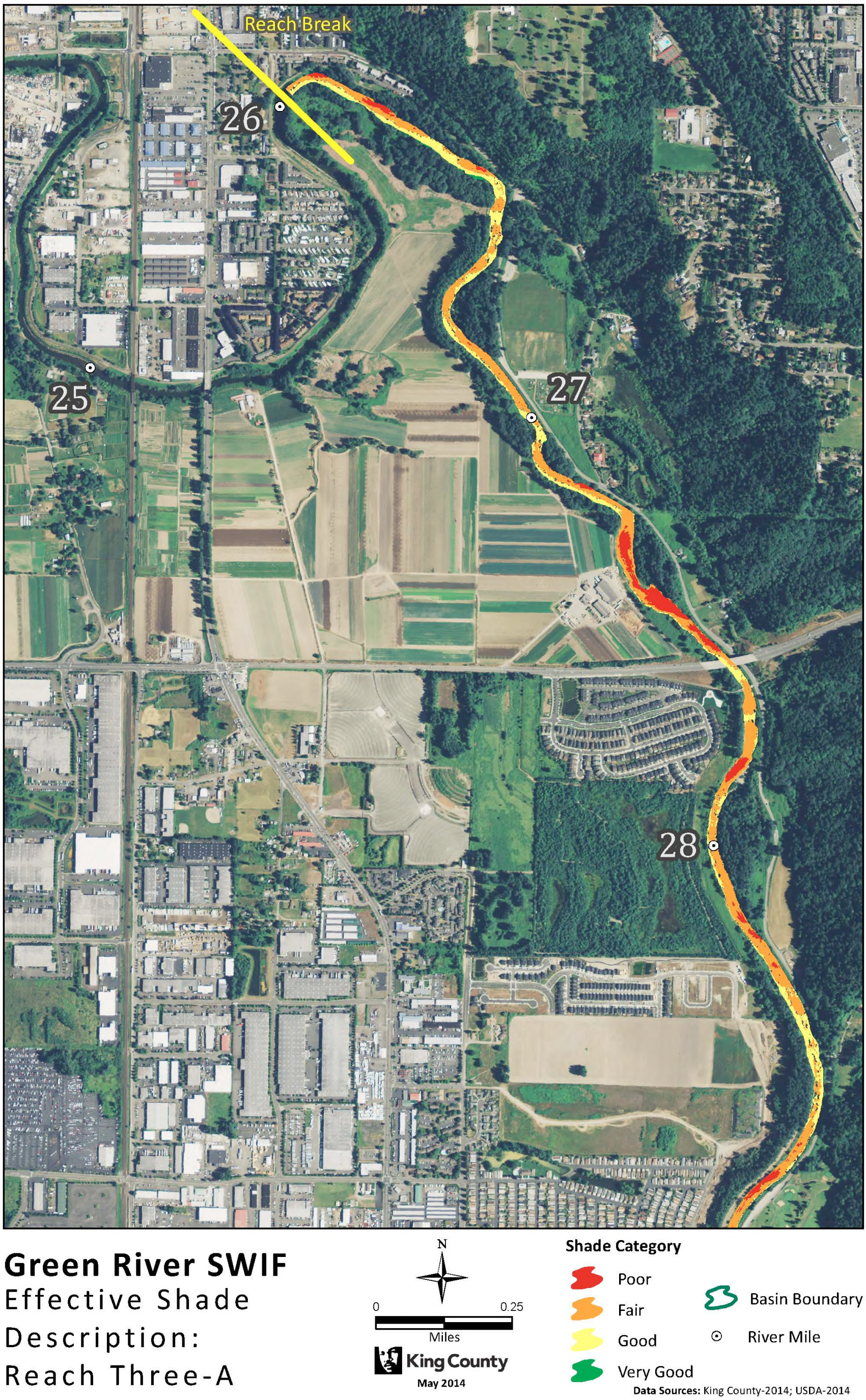


**Figure 5-7. Current effective shade conditions in the downstream half of Reach 3 (3A).**

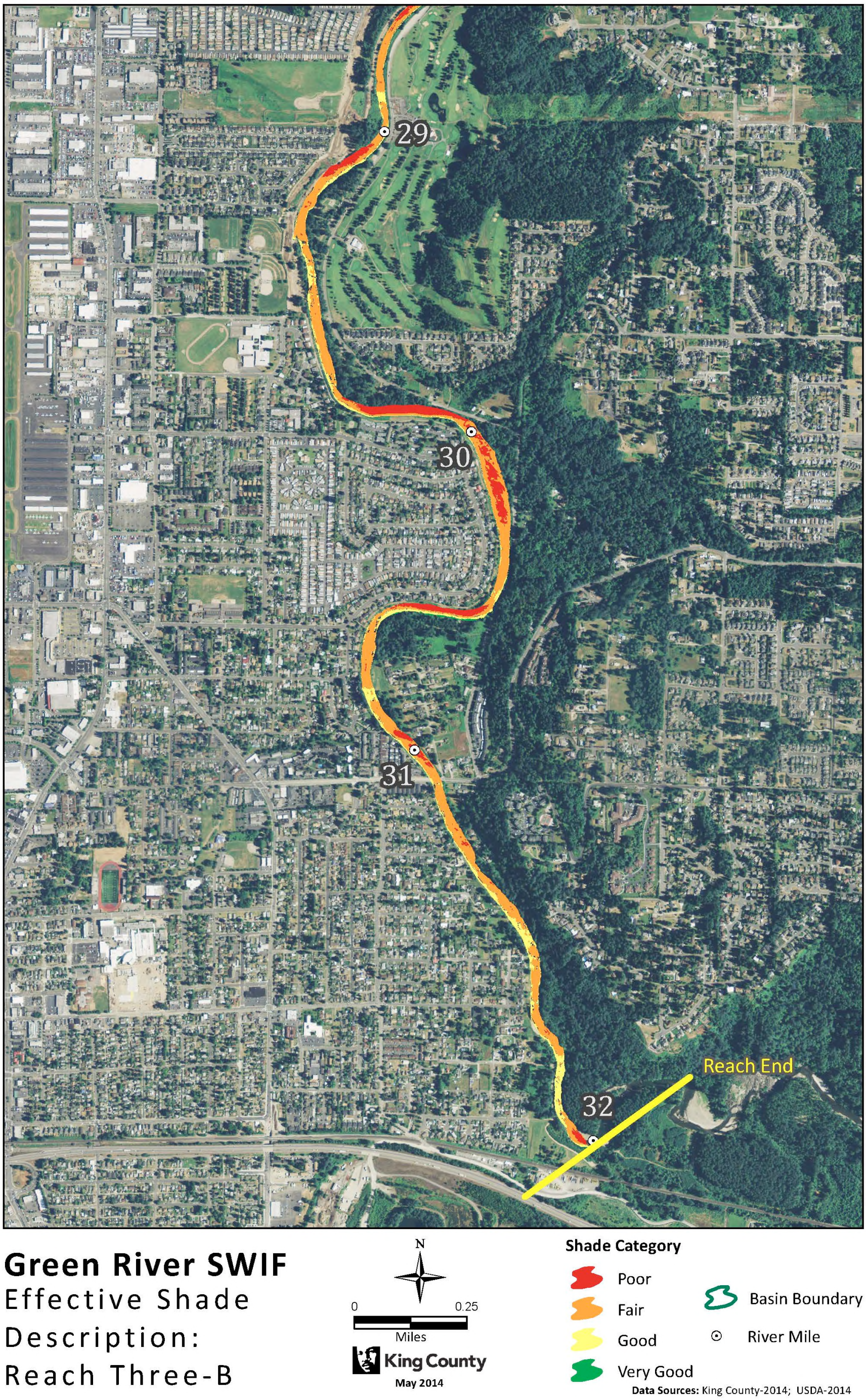


**Figure 5-8. Current effective shade conditions in the upstream half of Reach 3 (3B).**

## 5.3. Other Water Quality Parameters

The Lower Green River study area and its tributaries are listed on the 303(d) list of impaired waterbodies (Ecology 2014) for fecal coliform bacteria and dissolved oxygen (both require TMDLs), and there is concern about PCBs, mercury, and Bis-(2-Ethylhexyl) phthalate in the vicinity of the Boeing facility (approximately RM 16). Dissolved oxygen is of most serious concern for salmonids, but is generally confined to the lowest portion of the study area, approximately RM 11 and the Black River, although also in stretches within Springbrook Creek, Mullen Slough, and Mill Creek (Auburn). Efforts to reduce temperature will likely have benefits to dissolved oxygen as they are inversely related.

## 5.4. Conclusion

Water temperature is a critical limiting factor in the study area. High water temperatures stress adult salmon and reach lethal temperatures during hot summers. High temperatures also substantially reduce rearing habitat potential and cause juvenile salmonids to migrate downstream more quickly than is likely desired in the late spring and summer. Smolts that can feed and rear in the river on their way downstream enter marine waters at a larger size and are typically more fit to grow rapidly and survive better (Beamer and Larsen 2004).

However, from GIS shade modeling conducted for this study, even smaller patches of tall trees can increase shading. Good conditions result from greater than 100 foot wide fully forested riparian zones. However, even patches ranging from 50-100 feet in width can make incremental improvements in shading such as from poor to fair or fair to good. Also, the taller the trees are, the more shade that is cast. It is also very important to consider the long afternoon exposure to the sun from the west and ensure that even north-south trending stretches of river have forested riparian along the western shoreline. Native tree species that reach tall heights such as Douglas fir (*Pseudotsuga menziesii*), big-leaf maple (*Acer macrophyllum*), western red cedar (*Thuja plicata*), and Sitka spruce (*Picea sitchensis*) are particularly good at providing shade and are long-lived species that may be more resistant to breakage and wind-throw.

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# 6. OPPORTUNITIES

The WRIA 9 Green/Duwamish and Central Puget Sound Watershed Salmon Habitat Plan (WRIA 9 Steering Committee 2005) identified a number of priority actions for the Lower Green River. Since 2005, the WRIA 9 stakeholders have implemented several projects and updated their work plans with new priorities. For the purposes of the Green River SWIF, it will be important to identify potential aquatic habitat enhancement or restoration measures that can be undertaken within the context of simultaneously improving the reliability and function of flood management facilities, or in the context of increasing floodplain connectivity and function.

Specific to this assessment, the following aquatic habitat objectives are proposed with the limiting factors that could be addressed by the objectives (Table 16).

**Table 16. Habitat limiting factors, objectives for enhancement, and potential measures.**

| Habitat Limiting Factor | Enhancement Objectives | Restoration Measures |
|---|---|---|
| High water temperatures | • Increase forested riparian habitats for shading (including width, height, and density);<br>• Increase and maintain groundwater inputs/recharge | • Plant native riparian trees and shrubs in all feasible locations within 200 feet of river<br>• Retain and plant overhanging vegetation such as willows<br>• Protect White River groundwater flows<br>• Promote floodplain reconnection and groundwater recharge to augment and cool low flows |
| Lack of aquatic habitat diversity, particularly lack of pools and low-velocity edge habitats | • Increase aquatic habitat diversity, particularly low-velocity shallow water edge habitats and pools | • Remove or setback levees/revetments or reduce slope to increase shallow water and reduce velocities<br>• Do not put in new shoreline armoring structures where one doesn't already exist<br>• Place large wood in-channel mimicking natural wood structures (versus typical bank protection) where feasible to create hydraulic diversity and cover including low velocity areas and pools |
| Lack of floodplain and off-channel habitats | • Increase floodplain connections<br>• Restore existing tributary and slough habitats<br>• Restore floodplain wetlands | • Remove or setback levees/revetments and create benches<br>• Restore connections to floodplain wetlands<br>• Enhance tributary and slough habitats |

| Habitat Limiting Factor | Enhancement Objectives | Restoration Measures |
|---|---|---|
| Lack of riparian vegetation | • Increase large wood recruitment<br>• Provide shading and cover<br>• Increase insect and detrital production<br>• Provide and enhance wildlife corridors | • Restore riparian habitats to a mixture of trees and shrubs<br>• Reconfigure levees and revetments, to allow restoration of riparian vegetation in more natural proximity to water to improve likelihood of vegetation survival and functional contribution to salmon habitat |
| Modified hydrology and hydraulics | • Increase floodplain connectivity wherever feasible | • Promote floodplain reconnections for mainstem and tributaries to promote groundwater recharge and backwaters/off-channel hydraulics for fish rearing and refuge |
| Lack of spawning habitat | Restoring and enhancing sediment recruitment (particularly spawning gravels) by reconnecting sediment sources to the river will reduce channel down-cutting, increase shallow habitats, improve access to tributaries, and improve spawning habitat, thereby leading to greater juvenile salmon residence time, greater growth, and higher survival | • Set back levees to reconnect natural sediment sources<br>• Set back levees to allow for side channel formation and LWD recruitment<br>• Increase connectivity to sediment sources upriver |

Every possible location for removal of non-native vegetation and plantings of native trees and shrubs should be considered as water temperatures and lack of shading are critical problems both reaches. The west bank is particularly important. The following are preliminary locations identified in this existing conditions evaluation.

Preliminary locations to consider for a combination of reducing the slope of the bank along with riparian plantings and wood placement could include from RM 11 (Black River confluence) to 12 on both banks; right bank both upstream and downstream of the I-405 crossing with the possibility for wetland reconnection, floodplain and shallow water habitat; RM 13.9 left bank wetland; RM 15.9 right bank; RM 16.2 left bank; RM 16.5 to 17.2 left bank where new development may be occurring could be an opportunity for shallow sloping banks and riparian vegetation; RM 17 to 18 left bank; RM 18 to 19 riparian improvements with potential to reconnect to wastewater treatment mitigation site (wetlands and floodplain); RM 19 left bank wetland area; and RM 20 to 22 both banks. At approximately RM 22.5, the Agricultural Production District is present along the left bank and Mullen Slough and Mill Creek join the Green River at RM 21.7 and 23.9, respectively. There are opportunities for riparian restoration, off-channel habitat, and instream enhancement up to approximately RM 24. Additional opportunities include RM 24 right bank and the whole left bank along the south curve of Horseshoe Bend, including the narrow neck of land at RM 26; RM 26 to 28; tree planting from RM 30 to 31 left bank, and protection of patches of trees that exist along both banks.

Protecting and maintaining cooler water from the Middle Green and White River groundwater flows by increasing riparian shading starting at the upstream end of the Lower Green River is likely to be more effective than trying to shade only in the lower part of the study area. Shading cannot typically cool water down, but can maintain cooler temperatures for further distances downstream.

An analysis of bioengineered segments of levees in Appendix C indicates that when active repairs are made in a bioengineering context that the total vegetation cover increases and native vegetation species cover increases. However, this can take many years, so it is important to minimize loss of existing forested riparian or existing willow/overhanging vegetation until various planting, setback, or floodplain projects can catch up to provide shading and other functional benefits.

Appendix D includes a literature review of vegetation on levees. There have been incidences of wind-throw and tree breakage, but reducing levee slopes can provide a more stable growth medium for trees and trees on the lower portion of a levee slope are also more stable. Providing trees as close as possible to the river provides better shading potential as well as other benefits such as cover and detrital and insect inputs. Creating a planting bench could also be a desirable feature in a levee to reduce potential risks to the levee prism itself, while providing suitable native trees and shrubs in close proximity to the river.

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# APPENDIX A. HISTORIC VEGETATION CONDITIONS: INTERVIEWS

The following former and current King County staff interviews were conducted to capture a deeper understanding regarding river and floodplain management practices and their effects to vegetation conditions along the Lower Green River:

- Andy Levesque, December 4, 2013
- Steve Bleifuhs, Dec 5, 2013
- Ken Krank, Dec 9, 2013
- John Koon, Dec 9, 2013
- Dave Clark, Dec 12, 2013

Each interviewee was asked the following questions:

1. Please review this timeline of primary Lower Green River floodplain management chapters. Does this look correct? What is it missing? What are the approximate years (decades, etc.) associated with primary chapters or info that you suggest adding?
2. During what timeframe were you involved with Green River floodplain management and levee/revetment vegetation maintenance practices? What was/were your role(s)?
3. Please describe what the levees looked like, along the Lower Green River, during your tenure?
4. More specifically, what type of vegetation was typically found along the Lower Green River levees (grasses, blackberries, shrubs, trees, specific species types, etc.)? What were the typical levee vegetation maintenance practices (tree cutting, willow thinning, mowing, brushing)? Were these levee vegetation management practices applied uniformly to all portions of the levees, or to specific zones?
5. How often did these maintenance activities occur (e.g., annually, as needed, as requested)?
    a. Tree cutting
    b. Willow thinning
    c. Mowing
6. If mowed, how far down the slopes were the levees mowed? If the entire slope wasn't mowed, what was done with blackberry/reed canary grass and the lower end of the slope?
7. Was native woody vegetation left intact or cut? If cut, were rootwads removed?
8. If woody vegetation was removed, was the vegetation removal requested by another agency or was the decision to remove the vegetation internal to King County?
9. What was the geographical extent of the vegetation maintenance (i.e., only PL84-99 levees, entire lower Green, River Mile extent, etc.)
10. Is there anyone else we should talk to about historical conditions and vegetation management practices on the Lower Green?
11. To your knowledge, did levee failure (or damage?) ever occur as a result of the presence of woody vegetation? Do you have an opinion about whether shrubs, trees, or other woody

vegetation enhances or degrades (or does not affect) the structural stability of typical levees in the Lower Green

# APPENDIX B. RIVER BANK REPAIRS CONSTRUCTED BY KING COUNTY AND THE CORPS FROM 1990 TO 2013.

NOTE: Some projects occurred over several years; these projects are listed one time in the year the toe installation and planting (if applicable) were completed.

| Agency | Repair Name | Repair Year | Bank | D/S RM | U/S RM | Geogrids | Wood | Shrubs | Trees |
|---|---|---|---|---|---|---|---|---|---|
| KC | Van Warden | 1990 | Left | 13.70 | 13.80 | N | 0 | 0 | 0 |
| | 78th Avenue South | 1991 | Left | 24.86 | 24.87 | N | 0 | 0 | 0 |
| | NC Machinery/Liston | 1991 | Right | 13.70 | 13.77 | N | 0 | 0 | 0 |
| | Nursing Home | 1991 | Right | 26.10 | 27.10 | N | 0 | 0 | 0 |
| | Christiansen Trail | 1992 | Left | 14.15 | 14.21 | Y | 0 | 1800 | 0 |
| | Lone's 3rd Addition | 1992 | Left | 30.80 | 30.90 | Y | 6 | 960 | 0 |
| | Brannon | 1993 | Left | 30.30 | 30.30 | N | 0 | 0 | 0 |
| | Okimoto | 1993 | Right | 21.90 | 22.00 | Y | 0 | 3210 | 0 |
| | Dykstra/Lone's Addition | 1994 | Left | 30.50 | 30.90 | Y | 24 | 1440 | 0 |
| | Hamakami | 1994 | Right | 35.62 | 35.67 | Y | 80 | 3284 | 45 |
| | Plemmons U/S | 1994 | Right | 25.28 | 25.32 | Y | 10 | 700 | 0 |
| | Segale Riverward Levee | 1995 | Left | 15.20 | 15.40 | Y | 6 | 3600 | 0 |
| | 42nd Ave S | 1996 | Right | 7.30 | 8.00 | Y | 30 | 2025 | 0 |
| | Boeing RM 17.80 | 1996 | Right | 17.74 | 17.75 | Y | 8 | 625 | 0 |
| | Plemmons | 1996 | Right | 25.00 | 25.60 | Y | 12 | 600 | 0 |
| | Signature Pointe Lower | 1996 | Right | 22.19 | 22.28 | Y | 11 | 1600 | 0 |
| | Russell Road Lowest | 1997 | Right | 17.95 | 18.97 | Y | 14 | 900 | 0 |
| | Signature Point Upper | 1997 | Right | 22.60 | 22.80 | Y | 32 | 2650 | 0 |
| | Boeing RM 17.62 | 1998 | Right | 17.65 | 17.68 | Y | 8 | 369 | 60 |
| | Christian Brothers | 1998 | Right | 17.02 | 17.12 | Y | 25 | 3165 | 340 |
| | Russell Road | 1998 | Right | 17.90 | 17.92 | N | 0 | 400 | 0 |
| | Russell Road Lower | 1998 | Right | 18.76 | 19.50 | Y | 40 | 3530 | 225 |
| | Russell Road Upper | 1998 | Right | 20.31 | 20.39 | Y | 21 | 2303 | 170 |
| | White Swan (Southcenter Trail) | 2001 | Left | 12.25 | 12.27 | Y | 0 | 526 | 93 |
| | Desimone Levee | 2002 | Right | 15.10 | 15.50 | Y | 48 | 6330 | 680 |
| | Pipeline Levee | 2002 | Right | 21.80 | 21.90 | Y | 21 | 1960 | 50 |
| | Narita Levee | 2003 | Right | 21.80 | 21.90 | Y | 63 | 3700 | 320 |
| | Segale Levee | 2003 | Left | 15.16 | 15.20 | Y | 20 | 1397 | 0 |
| | Fenster Revetment Repair | 2004 | Left | 31.98 | 32.03 | Y | 49 | 2450 | 355 |
| | Strander Bridge Outfall Bank Stabilization | 2005 | Left | 13.02 | 13.02 | Y | 2 | 250 | 0 |
| | Breda/Horseshoe Bend 205 Levee Setback | 2006 | Right | 24.50 | 25.10 | N | 0 | 0 | 0 |
| | Somes-Dolan | 2006 | Right | 19.60 | 19.60 | N | 0 | 0 | 0 |
| | Frager Road Upper | 2007 | Left | 19.20 | 19.20 | Y | 18 | >200 | UNK |
| | Fenster Levee Setback and Floodplain Restoration | 2008 | Left | 31.80 | 32.00 | Y | 93 | 3019 | 982 |
| | Foster Golf Course FEMA | 2008 | Left | 9.90 | 9.90 | Y | 0 | 30 | 10 |
| | 42nd Ave South Repair | 2009 | Right | 7.60 | | N | 30 | 1785 | 40 |
| | Briscoe School Levee Repair | 2009 | Left | 16.33 | 16.44 | Y | 50 | >4772 | 0 |
| | Stoneway Lower Repair | 2009 | Left | 19.60 | 19.70 | Y | 71 | 4400 | 440 |
| | Reddington Levee Setback | 2013 | Left | 28.20 | 29.50 | Y | 410 | 7000 | 4200 |
| COE | Ratolo | 1990 | Left | 15.10 | 15.20 | N | 0 | 0 | 0 |
| | Home Depot (Tuk. 205) | 1996 | Left | 14.21 | 14.26 | Y | 3 | 1200 | 0 |
| | McCoy Breda | 1996 | Right | 24.40 | 24.80 | Y | 0 | 7200 | 0 |
| | Nursing Home | 1996 | Right | 25.60 | 26.60 | Y | 4 | 800 | 0 |
| | Galli's Section | 2008 | Left | 29.50 | 29.70 | Y | 28 | 4400 | 0 |
| | Kent Shops -- Narita Levee | 2008 | Right | 20.40 | 21.08 | Y | 154 | >1400 | UNK |
| | Myer's Golf Levee | 2008 | Right | 21.50 | 21.80 | Y | 63 | >1400 | UNK |
| | PL 87-99 Levee Rehabitilitation, Dykstra | 2008 | Left | 30.02 | 30.14 | Y | 0 | 1940 | 0 |
| | Tukwila 3 (U/S from S. 180th St.) | 2008 | Left | 14.37 | 14.57 | Y | 42 | >1700 | UNK |
| | Tukwila 5 (part of Segale) | 2008 | Left | 14.90 | 15.10 | Y | 35 | >1300 | UNK |
| | Horseshoe Bend Site 1 | 2009 | Right | 25.80 | 26.00 | Y | 10 | 4560 | 0 |
| | Horseshoe Bend Site 2 | 2009 | Right | 25.50 | 25.60 | N | 0 | 640 | 0 |
| | Horseshoe Bend Site 3 | 2009 | Right | 25.20 | 25.22 | N | 0 | 400 | 0 |
| | Horseshoe Bend Site 4 | 2009 | Right | 24.80 | 25.00 | Y | 35 | 4160 | 0 |
| | Horseshoe Bend Site 5 | 2009 | Right | 25.60 | 25.70 | N | 0 | 600 | 0 |

# APPENDIX C: RETROSPECTIVE ANALYSIS OF BIOENGINEERED FLOOD FACILITY REPAIR PROJECTS

## 1. Introduction

The King County River and Floodplain Management Section conducted a post-treatment analysis to test the assumption that bioengineered levees and revetments provide better habitat than traditional riprap-armored banks. The purpose of this pilot study conducted in 2013 and 2014 is to determine whether bioengineering has a significant effect on vegetative cover and riparian and in-channel habitat in the Lower Green River. The results will also inform the Lower Green River shoreline vegetation mapping effort (see previous section) being completed in support of the Green River SWIF.

Levees and revetments were built in the Lower Green River valley as flood and erosion protection facilities in the 1960s so that development could take place within the floodplain. Native gravels and soils were formed into a prism along the channel edge and covered with angular rock riprap at a steep grade, often with slopes exceeding 2:1. These levees and revetments were not planted with vegetation and were inhospitable to naturalized native plant growth because the riprap surface obscures or replaces mineral soils needed for seed germination and moisture retention. The over-steepened hardened banks created a highly degraded riparian area that does not provide many of the functions of a riparian area, but especially limits LWD recruitment, instream cover and shade. The levees and revetments also degrade the aquatic environment by disrupting natural channel migration, which creates a variety of habitats for fish and wildlife. When banks failed, repairs typically involved placing additional riprap.

King County began using bioengineering in bank stabilization repairs in the 1990s, with much success. Bioengineered banks are thought to provide better riparian and in-channel habitat than riprap-armored banks. Bioengineered bank stabilization techniques may vary slightly with the specific hydraulic conditions of a project site, but in the Lower Green River typically include large wood inserted in the facility toe that interacts with the wetted channel, willow plantings in the lower portions of the slope, and native mesic and upland plant communities planted on the middle and upper slopes, usually within geogrids.

In order to test the assumption that bioengineered banks with native vegetation incorporated into the design provide better habitat than riprap-armored banks, King County compared the habitat value of modern flood control facilities and traditional facilities by conducting a retrospective (i.e., post-treatment) analysis that included a characterization of riparian vegetation. Extensive post-treatment analyses have been shown to be an effective approach for examining the influence of project-driven modifications on salmon habitat (Grant et al., 1986; Roni et al., 2005). In this study modern bioengineered facilities were compared to older rock-armored facilities, and unarmored banks with established naturalized vegetation. Key questions were:

- Does total cover of native vegetation differ among bioengineered, rock-armored, and naturalized banks?
- Does the proportion of native to invasive plants differ among bioengineered, rock-armored, and naturalized banks?

- Does total cover of vegetation in the tree strata differ among bioengineered, rock-armored, and naturalized banks?

The study will continue in 2014 with analyses of additional vegetation metrics derived from a fall 2013 Lidar acquisition, as well as measurements of slow water edge habitat, fish use, and overhanging vegetative cover to determine whether bioengineering has had a significant effect on fish habitat and fish use in the Lower Green River. Results of the full fish habitat and fish use analysis will be presented in a separate King County report which is targeted for completion in December 2014.

## 2. Methods

We compared riparian vegetation communities on bioengineered levee repairs (treatment sites), 1960s-era rock facilities (control sites) and unarmored natural banks (reference sites). We conducted the riparian vegetation sampling in 2013 to determine the effect of bioengineering on native and invasive vegetation cover, and to inform (or "ground-truth") the SWIF land-cover mapping effort.

## 3. Site selection

We compiled Green River levee and revetment repair records from 1983 to present to be inclusive of all bioengineered bank treatments. The records include repair name, original construction year (if known), repair year, river mile extent, bank (left or right when facing downstream), agency responsible for design and construction, and principle design features such as toe construction type, amount of large wood installed, use of vegetation for bank stability (geogrids), and number of planted trees and shrubs.

We then selected study sites from the list of repair records to obtain a minimum of 15 treatment sites to sample. Treatments included bank repair projects that had wood installed at the toe and native vegetation planted on the bank. We grouped each treatment site with a control site that was located nearby. The control site has the same river alignment (inside bend, outside bend, or straight) as the treatment site wherever possible. We also selected a reference site, where possible, so we could compare flood control facilities with unarmored stream banks that have naturalized vegetation. Although few sites in the highly modified Lower Green River valley remain unaltered by human activities such as logging or agriculture, we tried to select reference sites that had no known current or historic rock armoring on the bank.

We sampled a total of 22 treatment-control pairs for vegetative cover. Of these 22 sites, 15 also had a reference (natural bank) site associated with them. Among the 59 sites selected, 30 were within PL 84-99 Levee Systems (Table C-1). Because this study design was developed to test the differences among treatment types as opposed to among Levee Systems, not all Systems were sampled proportionally. Levee Systems 1 and 2 were sampled more heavily than 3, 4, and 5 because they have a greater total proportion of the total levee systems length. Additionally Levee Systems 3, 4, and 5 did not have reference reaches that met the criteria described above. We sampled 3-4% of the total length of Systems 1 and 2 which cover 62% of the total length of all PL84-99 systems, and 1-4% of the length of Systems 3, 4, and 5 which cover 38% of the total levee systems length (Table C-1).

**Table C-1. Number of sample sites located within and outside of PL 84-99 Levee Systems.**

| PL 84-99 Levee Systems | Control | Reference | Treatment | Total |
|---|---|---|---|---|
| **1: Left Bank, RM 12.44-16.7** | 5 | 1 | 4 | 10 |
| **2: Right Bank, RM 14.5-22.04** | 3 | 1 | 8 | 12 |
| **3: Right Bank, RM 22.77-23.18** | 1 | | | 1 |
| **4: Right Bank, RM 24.25-26.09** | 2 | | 3 | 5 |
| **5: Left Bank, RM 28.6-30.79** | | | 2 | 2 |
| **Non PL 84-99 Facilities** | 11 | 13 | 5 | 29 |
| **Total** | **22** | **15** | **22** | **59** |

### 4. Vegetation transects

We used the "point intercept along transects" method for sampling vegetative cover (Elzinga et al. 1998). We selected one 25-meter long transect for each distinct plant community at a site. The number of transects per site therefore varied because some sites were a monoculture (one transect) whereas others had distinct vegetation communities at different locations on the bank (up to five transects: toe, lower slope, bench, midslope, upper slope). Transects consisted of a tape measure placed parallel to the river flow; data were collected at 25 evenly-spaced points along the tape measure proceeding in the downstream direction of flow. The starting point of each transect was in the same lateral location as we moved up the slope. We used the following guidelines to select transect locations:

- Treatment sites: the middle of the best representative section of the installed vegetation.
- Control sites: a transect starting point randomly selected using GIS software.
- Reference sites: the middle of the most homogeneous and representative naturalized banks close to treatment and control sites.

We recorded the species of plant foliage intersecting the vertical plane extending from the ground surface through the canopy at points located at one-meter intervals along the tape measure transect, starting at a randomly generated number between 0.0 and 1.0 (25 points per transect). We used a plumb bob to sample plants below waist height and a GRS Densitometer to sample plants above waist height. A "hit" for a particular plant species was recorded each time the plumb bob contacted a piece of foliage and each time the densitometer crosshairs intercepted foliage.

Species, stratum, and type were recorded for each "hit". Strata were forb, shrub (<10 cm diameter at breast height [dbh] and <5 m high), and tree (≥10 cm dbh and ≥5 m high); types were native, invasive, and ornamental. Pasture and erosion control grasses were lumped together as "unknown grass" and willows were not identified to species but merely as *Salix sp*. We recorded all "hits" regardless of overlap. One species could be present more than once at a single point only if that species was observed in more than one stratum (i.e., willow as a shrub and a tree); a species was only counted once per stratum per point.

We measured the width of each plant community by running a tape vertically up the slope and marking the start and end points of each community type. We used the width measurement to quantify the relative importance of each plant community because we combined the data from multiple transects at a site.

Some sample sites were inaccessible because they were too steep or dangerous to walk on, and others had vegetation that was too thick to reasonably run transects. At these facilities, we ran a transect at the top of the bank (or along the opposite bank if visibility was better) and used binoculars and best professional judgment to estimate vegetation cover at each point along the transect.

### 5. Data Analysis

Plant species were assigned one cover value per site. Species "hits" at each point were combined along transects and data from multiple transects were weighted and combined using the following equation:

*Percent cover of a plant species = (H/25*100)*WF*

where H (hits) is the number of times the species was sampled along the transect, 25 is the number of sample points, and WF is the weighting factor, which was obtained by dividing the width of the vegetation community containing the species by the sum of the widths of all of the vegetation communities at the site.

Because the data were normally distributed, we used a randomized block design ANOVA to compare vegetation metrics among treatment, control, and reference sites (Zar 2010). Blocks consisted of treatment-control-reference triplicates (or treatment-control pairs when reference sites were unavailable) located in close proximity. The purpose of the randomized block design was to account for bias that may result from the location of sites on the Lower Green River, regardless of site type. For example, a change in soil type along the river may influence vegetation and lead to mistakes in data interpretation if unaccounted for. The Tukey post hoc test was used to identify the source of significant differences (Zar 2010).

The following vegetation metrics were compared: total vegetative cover, the ratio of native to invasive vegetative cover, and total native tree cover. We could not include "time since treatment" in the analysis as a covariate because this information was unavailable for control and reference sites. We used an independent samples t-test to compare percent vegetative cover between treatment sites that are and are not enrolled in the PL84-99 program, and between treatment site repairs constructed by King County and those constructed by the Corps.

### 6. Results

We calculated metrics for each PL84-99 levee system and segment sampled (Table C-2), as well as the complete set of Lower Green River sites sampled. Results for PL84-99 Levee Systems, only, are presented below with results for the entire set of study sites presented in subsequent sections.

### 7. PL 84-99 Levee Systems

Levee systems in the Lower Green River showed consistent vegetation quality patterns, with control sites having substantially less total native vegetation and tree cover than reference and treatment sites (Table C-2) and substantially more invasive vegetation than treatment sites. Control sites typically had no native tree cover, with a maximum cover of 6.8%. Invasive vegetation cover on control sites ranged from 73.4% to 203% with the rocky slopes dominated by blackberries with reed canary grass at the toe of the slopes. In contrast, the two reference sites measured had high native tree cover along with high invasive cover in the understory, again typically blackberries and reed canary grass. Treatment sites had a range of native tree cover, with about half of the sites averaging greater than 25% cover; treatment sites on average had less invasive vegetation than control or reference sites. Because this study design was developed to evaluate differences among treatment types for the length of the Lower Green River as opposed to among levee segments, there are not enough sample sites within the PL 84-99 Levee Segments to draw statistically supported conclusions about these patterns. The patterns for these sites do, however, appear to be consistent with the patterns for the Lower Green River as a whole, which are described in subsequent sections.

**Table C-2. Percent native, invasive, grass, ornamental and no vegetation cover at PL 84-99 Levee System Segments.**

| Levee System | Levee Segment | Category | N | Native Trees | Native Shrubs | Native Forbs | Invasive (all strata) | Grass | Unknown/ Ornamental | No Vegetation | % System Measured | % of All Systems |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Tukwila 205 | Treatment | 4 | 9.6 | 65.8 | 1.4 | 66.4 | 40.6 | 0.0 | 0.9 | 4 | 26% |
| | | Control | 5 | 0.6 | 34.2 | 2.2 | 114.7 | 3.0 | 1.9 | 0.0 | | |
| | | Reference | 1 | 110.3 | 18.7 | 0.0 | 215.7 | 2.4 | 0.0 | 0.7 | | |
| 2 | Boeing | Treatment | 1 | 53.1 | 53.1 | 0.0 | 57.4 | 18.9 | 0.0 | 0.0 | 3 | 36% |
| | | Reference | 1 | 72.0 | 6.4 | 0.0 | 186.4 | 0.0 | 26.7 | 0.0 | | |
| | Desimone-Briscoe School | Treatment | 2 | 69.8 | 116.4 | 2.0 | 15.2 | 4.9 | 2.4 | 0.0 | | |
| | | Control | 1 | 0.0 | 0.0 | 0.0 | 203.6 | 0.0 | 0.0 | 0.0 | | |
| | Lower Russell-Holiday Kennel | Treatment | 1 | 108.0 | 100.0 | 12.0 | 24.0 | 0.0 | 0.0 | 0.0 | | |
| | Upper Russell-Somes Dolan | Control | 1 | 0.0 | 0.0 | 6.2 | 105.8 | 0.0 | 3.6 | 5.5 | | |
| | Kent Shops-Narita | Treatment | 2 | 46.7 | 71.4 | 2.3 | 22.8 | 57.0 | 2.5 | 0.0 | | |
| | | Control | 1 | 0.0 | 29.7 | 0.0 | 106.9 | 3.4 | 0.0 | 0.0 | | |
| | Myers Golf | Treatment | 2 | 26.3 | 59.4 | 0.0 | 23.0 | 49.6 | 0.0 | 6.5 | | |
| 3 | Signature Point | Control | 1 | 0.0 | 30.3 | 0.0 | 73.4 | 0.0 | 0.0 | 20.9 | 1 | 13% |
| 4 | Horseshoe Bend | Treatment | 3 | 11.8 | 21.4 | 0.0 | 154.5 | 0.0 | 0.0 | 0.0 | 4 | 12% |
| | | Control | 2 | 6.8 | 32.6 | 0.0 | 121.6 | 32.1 | 2.1 | 0.0 | | |
| 5 | Dykstra | Treatment | 1 | 4.0 | 62.7 | 0.0 | 44.0 | 89.3 | 0.0 | 0.0 | 1 | 13% |
| | Galli's | Treatment | 1 | 0.0 | 46.9 | 0.0 | 58.5 | 41.8 | 0.0 | 8.7 | | |

% System Measured = proportion measured relative to total system length
% of All Systems = proportion of levee system length to total length of all levee systems combined

### 8. Levee System 1

Levee System 1 includes a suite of levee segments on the left bank looking downstream, collectively known as Tukwila 205, that protect roughly 4.25 river miles of primarily industrial and commercial land in the city of Tukwila. Native tree cover is relatively low in this system due to steep rock-lined banks, a substantial amount of tree cutting and willow thinning over the past decade in order to meet vegetation performance standards of the PL84-99 program, and two relatively new repairs (Table C-2). The tree cover that does exist on bioengineered sites is predominantly willow and other aggressive native plants that can tolerate repeated cutting (Figure C-1). Control sites in this reach are largely dominated by blackberry on the slopes and reed canary grass at the slope toe (Figure C-2).

**Figure C-1. Control site 8-C**

**Figure C-2. Treatment site 4-T**

### 9. Levee System 2

At just over seven and a half river miles, Levee System 2 is the longest of the Green River levee systems (Table C-2). This system protects high value business and industrial properties on the right bank through the City of Kent and Tukwila. The reference site in this reach shows typical naturalized bank conditions with a single row of tall trees at the top of the bank and middle and lower slopes of the bank covered in invasive blackberry and reed canary grass (Figure C-3). Such conditions are valuable in terms of river shading, but do not provide as high quality stream cover and food inputs for salmon as would a lower slope comprised of a variety of native shrubs. In contrast, several treatment sites in the system had excellent native shrub communities and tree cover comparable to the reference reach (Figure C-4). These treatment sites are subject to PL 84-99 vegetation performance standards and run the risk of having vegetation communities further degraded by tree cutting.

**Figure C-3. Reference site 10-R**

**Figure C-4. Treatment site 5T**

**10. Levee System 3**

Levee System 3 is the shortest of the systems at less than one river mile. Located in the City of Kent, this system protects a substantial apartment community of 624 residences called Signature Pointe and a few other small residential communities. The system is comprised of 1960s era rock revetments dominated by invasive blackberry shrubs with a few patches of native willow (Table C-2, Figure C-5). There is very little riparian function provided by these plant communities.

**Figure C-5. Control site 18-C**

### 11. Levee System 4

Levee System 4, known as "Horseshoe Bend" due to its unique shape includes several 1960s rock facilities, a few which have had repairs installed in 2009 by the Corps (Table C-2). Older King County repairs along Horseshoe Bend were not sampled. These facilities protect a mixed use landscape that includes businesses, light industrial warehouses, and a mobile home park. Tree cover is very low, possibly because the planting occurred more recently (Figure C-6). Control sites in the system are typical, dominated by blackberry and reed canary grass (Figure C-7).

**Figure C-6. Treatment site 21-T**

**Figure C-7. Control site 20-C**

### 12. Levee System 5

Levee System 5, comprised of Brannan Park-Reddington, Galli's, and Dykstra, is just over two miles long and primarily protects suburban single family housing in the City of Auburn (Table C-2). The majority of segments sampled in this system have undergone recent repair. The Reddington levee in this reach was not included in this study as it was under repair in 2013. The Dykstra and Galli's revetments in the reach were repaired by the Corps in 2008 and feature young shrubby vegetation (Figures C-8 and C-9).

**Figure C-80 1. Treatment site 23-T**

**Figure C-9. Treatment site 24-T**

### 13. Comparison of Total Vegetative Cover Among Treatment, Control, and Reference Sites

We found a significant effect of site category (treatment, control, reference) on percent total vegetative cover at the $p < 0.05$ level [$F(2, 28) = 13.49$, $p = 0.000$] (Figure C-10). Post hoc comparisons using the Tukey HSD test indicated that the mean percent vegetative cover for reference sites (221%) was significantly higher than the mean score for treatment sites (186%, $p = 0.044$) and control sites (149%, $p=0.000$). The mean percent total vegetative cover was also significantly higher at treatment sites than control sites ($p=0.033$).

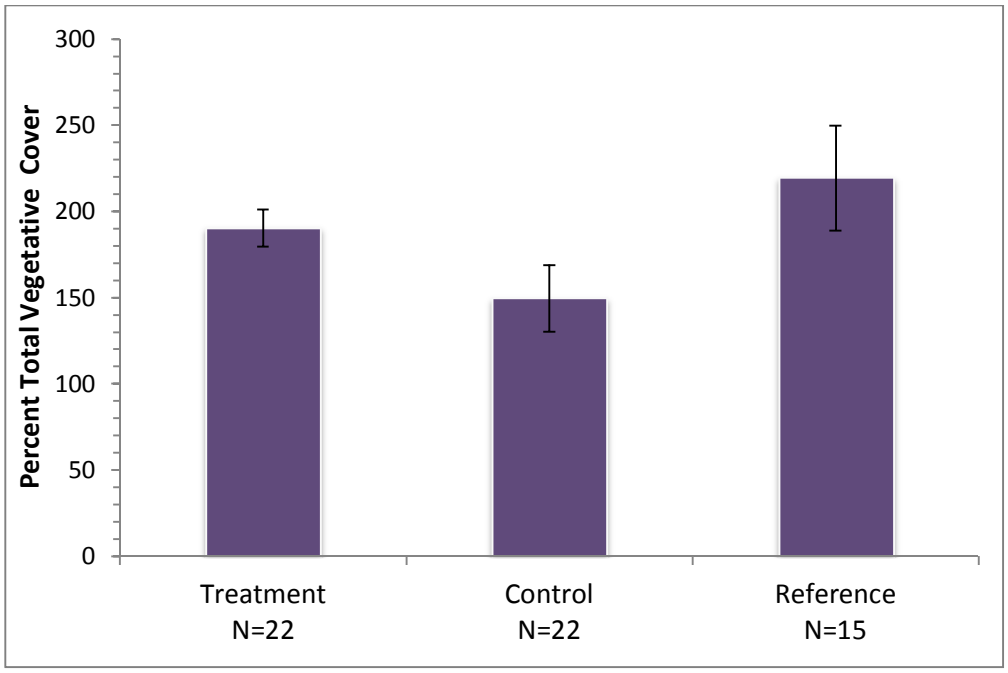


**Figure C-10. Percent total vegetative cover at treatment, control, and reference sites. Error bars represent 2SE. Sample size is indicated below each category on the x-axis.**

### 14. Comparison of Native to Invasive Plant Cover

Native vegetative cover followed the same pattern as total vegetative cover. We found a significant effect of percent native vegetative cover at the $p < 0.05$ level for the three site types [$F(2, 28) = 23.54$, $p = 0.000$]. Post hoc comparisons using the Tukey HSD test indicated that the mean percent native vegetative cover for reference sites (148%) was significantly higher than the mean score for treatment sites (88%, $p=0.007$) and control sites (26%, $p = 0.000$). The mean percent native vegetative cover for treatment sites was also significantly higher than control sites ($p = 0.004$) (Figure C-11).

Percent native vegetative cover was significantly higher at treatment sites that were not enrolled in the PL84-99 Program compared to sites that were enrolled in the program ($p = 0.037$), but total vegetative cover and invasive cover were not significantly different between the two groups ($p=0.399$ and $p = 0.582$, respectively).

Percent native vegetative cover was significantly higher at treatment sites constructed by King County compared to sites that were constructed by the Corps ($p = 0.001$). Total vegetative cover and invasive cover were not significantly different between the two groups ($p=0.638$ and $p = 0.561$, respectively).

The mean proportion of native to invasive vegetative cover was affected by site category at the $p < 0.05$ level [$F(2, 28) = 34.85$, $p = 0.000$] (Figure C-12). Post hoc comparisons using the Tukey HSD test indicated that the mean proportion of native to invasive vegetative cover for control sites (0.15) was significantly lower than the mean score for treatment sites (0.60, $p = 0.000$) and reference sites (0.69, $p = 0.000$). The mean proportion of native to invasive vegetative cover was not significantly different in treatment and reference sites.

Taken together, these results suggest that vegetative cover in the Lower Green River was strongly influenced by the presence of flood protection facilities, as well as the character of those facilities. Facilities that included bioengineering had significantly higher vegetative cover than traditional rock-

lined sites, but sites with natural banks had significantly higher vegetative cover than sites with flood control facilities even if those facilities included bioengineering. Although the younger age of vegetation on bioengineered sites undoubtedly contributed to this result, it will be important to monitor vegetative cover over time to see whether bioengineered sites approach the condition of reference sites as they mature. Also, removal of native trees and shrubs when they exceed Corps vegetation standards very likely contributed to lower native vegetative cover at PL84-99 facilities. Vegetation on control sites was regularly disturbed by mowing and cutting, preventing the establishment and growth of mature woody plants. Moreover, the rock armor typical of these sites prevents germination of native seeds and creates drought conditions during summer months.

The two most dominant invasive species, Himalayan blackberry and reed canary grass, tend to colonize and dominate sites in full sun with poor soils such as steep rock-covered slopes more successfully than native vegetation. This is likely why the control sites had the highest invasive vegetation cover. Grass cover is likely higher at the treatment sites because the Army Corps of Engineers used annual erosion control grass at the 11 levee repairs completed in 2008 and 2009. The upper slopes at these sites were only seeded with grass; shrubs and trees were planted on the lower slopes and mid-slope benches.

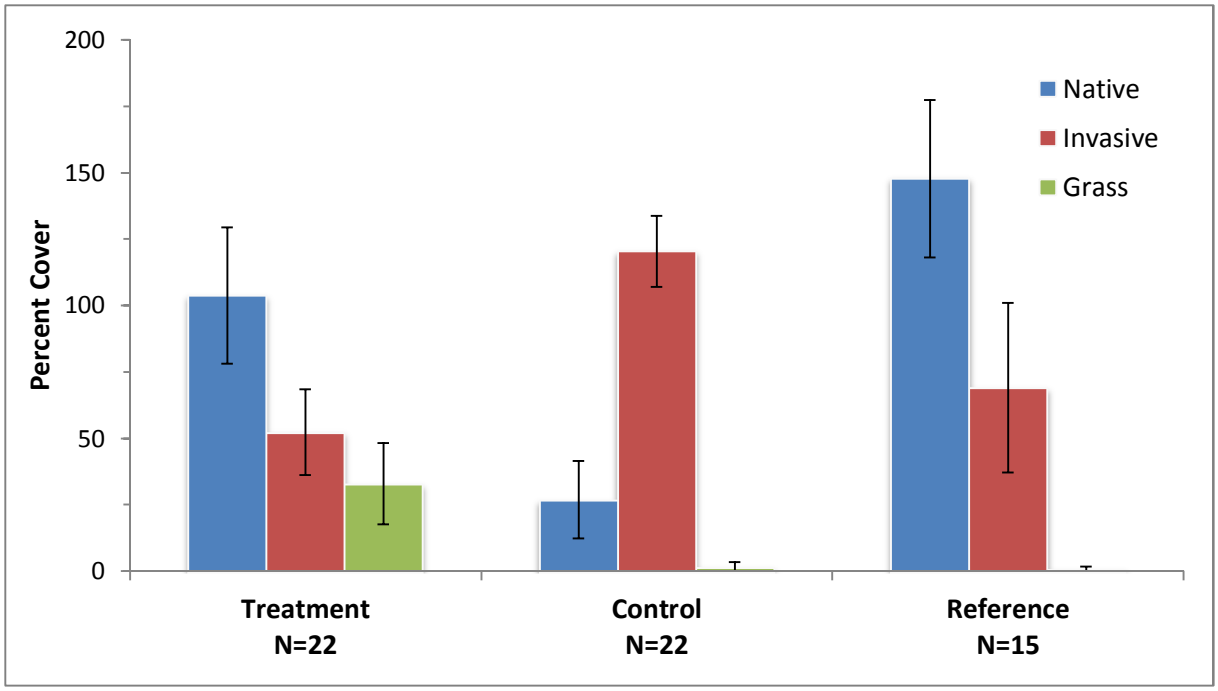


**Figure C-11. Percent vegetative cover at treatment, control, and reference sites by plant category. The native and invasive categories include tree, shrub, and forb strata, and reed canary grass is included in the invasive category. The grass category includes all grasses other than reed canary grass, including those used for erosion control following construction. No vegetation, ornamental, and unknown categories were included due to very low average percent cover. Error bars represent 2SE. Sample size is indicated below each category on the x-axis.**

### 15. Native Tree Cover

Native tree cover was influenced by site type at the $p < 0.05$ level [$F(2, 28) = 20.807$, $p = 0.000$] (Figure C-12). Post hoc comparisons using the Tukey HSD test indicated that mean native tree cover for reference sites (86%) was significantly higher than the mean score for treatment sites (27%, $p = 0.000$) and control

sites (12%, p = 0.000). Mean native tree cover was not significantly different in treatment and control sites.

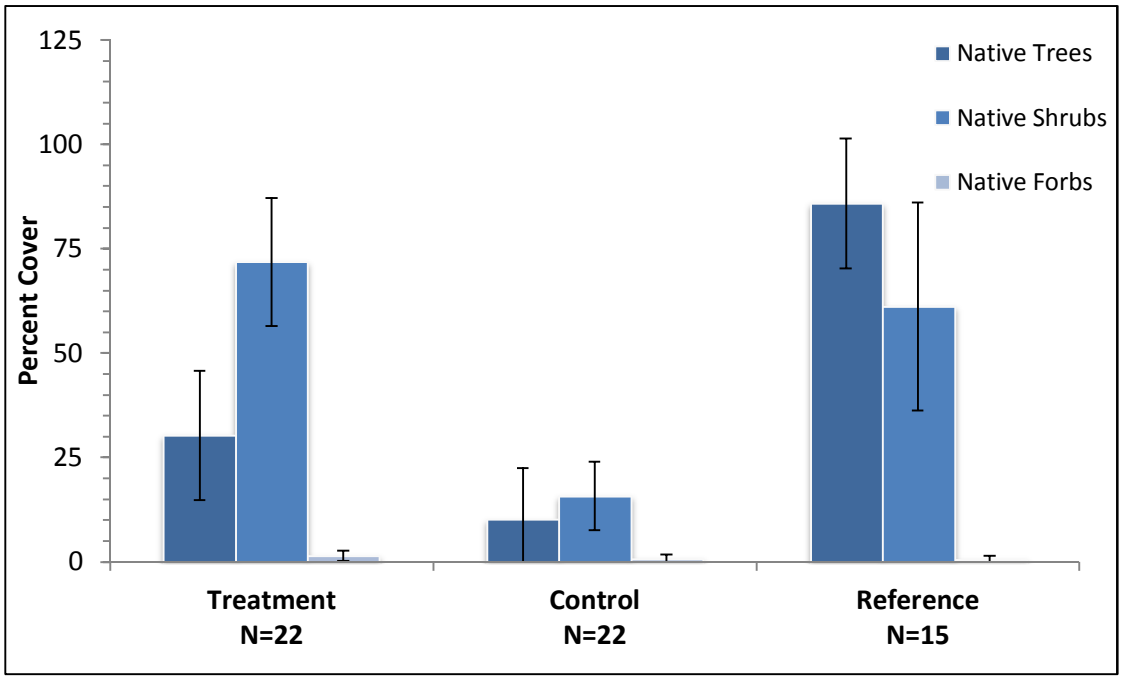


**Figure C-12. Percent cover of native vegetation strata at treatment, control, and reference sites. Error bars represent 2SE. Sample size is indicated below each category on the x-axis.**

Mature native trees were much more abundant on reference sites than treatment sites, which is to be expected because trees planted recently on treatment sites have not had time to grow large and also because many trees were removed from bioengineered treatment sites once they exceeded Corps vegetation standards. Because size was used to distinguish between trees and shrubs in our study, the proportion of trees and shrubs in treatment sites may change to more closely approximate that of reference sites if the trees are allowed to mature. Poor soils and chronic disturbance from routine mowing and cutting prevent establishment of a native plant community on control sites.

### 16. Conclusions and Recommendations

Total vegetation cover, proportion of native and invasive cover, and native tree cover differed between reference, treatment and control sites. Reference sites had the highest total cover, native vegetative cover, proportion of native to invasive plants, and percent cover of native trees, though there was not a significant difference in proportion of native and invasive plants between reference and treatment sites. These results are consistent with qualitative observations as well as descriptions of Lower Green River levees given by current and former King County Green River managers (Chapter 1). The evidence suggests that reference sites provide the best riparian habitat, while bioengineered facilities do provide better habitat in terms of native plant community composition and native tree cover than traditional rock-armored banks. The difference in total vegetation cover and native tree cover between reference and treatment sites is likely largely a product of tree management (PL84-99 cuttings) and age of vegetation. Assuming tree cutting was discontinued, bioengineered facilities could be expected to attain desirable habitat features of reference sites over time.

Time since treatment was not analyzed as a covariate, and we hypothesize that bioengineered treatment sites will more closely resemble reference sites over time if woody native vegetation is not removed. This phenomena would be a good candidate for future study. Additionally, we did not have enough statistical power to compare PL84-99 levee systems or detect differences among maintenance strategies (e.g., no native vegetation removal, mowing, selective tree cutting). Future studies could investigate the effects of maintenance strategies on native vegetative versus invasive species cover, as well as treatment impact on structural stability.

## 17. References

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# APPENDIX D: VEGETATION ON LEVEES: ANNOTATED LITERATURE REVIEW (BY ASHLEY ADAMS)

## 1. Introduction

This report incorporates the findings of a literature review that includes analysis of documents from peer-reviewed journals, published books, and gray literature including agency technical reports, engineering manuals, as well as internet and newspaper articles. The goal of this report is to determine the current status of research related to woody vegetation on levees and identify knowledge gaps.

Between 2007 and 2009, the USACE Engineering Research and Development Center performed an extensive literature review of levee vegetation (USACE, 2010). Their review included information pertaining to both woody and non-woody vegetation in variety of settings. The full report released in December of 2010 includes references to many important research studies and documents outlining the complexity of vegetation and soil erosion. In order to focus our literature review on information pertaining strictly to levees, we reviewed the references coded LEVVEG in the USACE report, indicating a connection between levees and vegetation. In addition, we did a search for information made available after USACE performed their literature review in order to capture new research results.

The goal of this review was to outline where woody vegetation appears to help or hinder levee integrity while discerning where future research is needed to fill existing gaps, with special emphasis being placed on the Puget Sound Basin and King County. This will enable policy makers to create sound guidelines based on evidence-based research so that levees can be managed effectively for public safety as well as environmental protection.

The objectives of this report are:

- To synthesize literature regarding woody vegetation and the effect on the structural integrity of levees.
- To describe where woody vegetation seems to help or hinder levee stability.
- To guide future levee vegetation research in King County.

## 2. Methods

A review of the literature was conducted to determine existing policies and research data pertaining to woody vegetation and the structural stability of levees. The review included documents from peer-reviewed journals, published books, governmental and non-governmental documents, letters and reports, policy papers, engineering standards, as well as other documents available on the internet.

First, a closer examination of the USACE literature review was performed to pull out the most relevant documents pertaining to woody vegetation and levees. To accomplish this goal, select categories from the bibliography were entered into an Excel document and then filtered to obtain a general summary of the information. The categories we used for this are as follows: type of article, primary author, title, USACE code, study type (empirical, model or both), soil type, study location, and vegetation type. Results from this examination are outlined in Table D-1. The USACE literature review consisted of 254 references, each of which was assigned a reference code to describe the main emphases of the study. 51 were coded with the primary category LEVVEG, denoting that the document was pertinent to levee

vegetation impacting levee integrity. We choose to only examine these references more closely to include pertinent information in this review about woody vegetation and levees. Several of these documents are included in the bibliography, but may not be presented in this document for various reasons. Some of these reasons include lack of information pertaining to woody vegetation and levees (e.g. only studied grass), outdated policies regarding levee vegetation, document was a newspaper/internet articles that may not have provided significant information relevant to the purpose of this review, or the document could not be located or obtained in time for this review.

**Table D-1. Publication source in U.S. Army Corps Literature Review (USACE 2010)**

| **Type of Publication** | **Number** |
|---|---|
| *In Peer-Reviewed Journals:* | |
| Empirical Research | 107 |
| Model | 24 |
| Model and Empirical Research | 12 |
| Review Article | 15 |
| Not described | 1 |
| **Subtotal:** | **159** |
| *In Sources other than Peer-Reviewed Journals:* | |
| Journals | 1 |
| Review Paper | 5 |
| Presentation, Conference, or Workshop Paper | 28 |
| Guidelines | 4 |
| Thesis/Dissertation | 1 |
| Published Book | 15 |
| Government (Federal/State) | |
| Empirical Research | 8 |
| Model | 1 |
| Model and Empirical Research | 1 |
| Legislation | 2 |
| Review Article | 11 |
| Technical Manual | 10 |
| News/Internet Articles | 8 |
| **Subtotal:** | **95** |
| **Grand Total:** | **254** |

In addition to looking at the LEVVEG documents described above, we searched for literature released since January 2008 in order to capture new information that would not have been included in the USACE literature review report. Keyword searches included various combinations of the following terms: vegetation, woody vegetation, levee, levee stability, levee vegetation, dike, dike stability, Army Corps, bank stability, riparian vegetation, vegetation policy, and vegetation on levees. The online databases used to find relevant literature pertaining to woody vegetation and levee stability included Web of Science ISI and Google Scholar. In addition, searches were done on governmental, non-governmental, and inter-governmental websites for related publications.

## 18. Findings

### a. Review of USACE Literature Review

Although the USACE literature review was extensive and robust, this report synthesizes the documentation from a more focused perspective to assess the literature specific to woody vegetation on levees. Of the 51 references coded with LEVVEG as the primary category in the USACE report, there were 11 journal articles, two books, 16 government publications, six news articles, 12 conference proceedings, two reviews, and two international guidelines. Of these, 10 of them could not be located online nor requested in time for this literature review, three of them only addressed grass on levees and not woody vegetation, one did discuss woody vegetation and levees, but focused on chemistry and nutrient uptake, and three of them are addressed elsewhere in this document and therefore are not summarized in this section. Additional information from these documents is included in the discussion portion of this report. An annotated review of the literature reviewed is presented below.

### b. Peer-reviewed journal articles

A study conducted by Dwyer et al (1997) found that there was an inverse relationship between width of riparian woody vegetation along a levee and the length of the levee failure following the Midwest flood of 1993; as vegetation width increased, length of failure decreased. The data suggest that a woody riparian corridor between the river and the levee averaging at least 54.6 meters (179 feet) in width is necessary to be effective in minimizing the average failure of the levee as compared to a non-wooded riparian corridor. When the corridor was less than 54.6 meters in width there was no difference. However, there was a significant increase in levee stability with a woody riparian corridor of at least 91.5 meters in width resulting in a 68% decrease in the length of the levee failure.

The research team of Shields and Gray (1992) investigated the influence of woody vegetation on the structural integrity of sandy levees along the Sacramento River, California. They collected field data including soil properties and botanical surveys, and applied appropriate parameter values to perform seepage and mass stability analyses. The results indicated that open voids in the soil were not attributable to roots and that roots reinforced the levee soil and increased shear resistance. Even low root concentrations increased the Factor of Safety (FOS) significantly, due to the small increases in soil shear strength caused by the roots. They concluded that woody shrubs and small trees on levees would enhance its structural integrity.

A similar study reported by Shields (1991) investigated woody vegetation and stability of riprap revetments along the Sacramento River following the flood of 1986. By mapping pre and post-flood vegetative cover using inspection records, he found that of the five revetments enrolled in the PL 84-99 program that sustained damage during the 1986 flood, none of them supported woody vegetation before or after the flood. He also discovered that the damage rates for revetments with woody vegetation tended to be lower than for unvegetated revetments of the same age and material, located on banks of similar curvature. Using chi-squared statistics, he found that damage rates were greater for pre-1950 revetments and concluded that vegetation did not appear to affect revetment durability.

### c. Government documents

The government documents included in this review fit into one of two categories: 1) levee vegetation guidelines and 2) research reports. A brief summary of each is provided below and excerpts from them are included in the discussion portion of this report where appropriate.

#### *i. Levee vegetation guidelines*

Several of the LEVVEG government documents are particular to the State of California including the California Water Code, which acknowledges the benefits of levee vegetation and addresses the standards developed by the State of California and USACE to minimize its removal and encourage replanting on levees (State of California, 2008). It also acknowledges the additional costs to maintain vegetation on levees and outlines who is responsible for these costs. Also, the 1988 document, *Interim guidance for vegetation on flood control le*vees under Reclamation Board Authority, was prepared to provide basic standards for vegetation on levees while they conducted a five-year demonstration project to study the effects of various vegetation types on levee stability (California Reclamation Board, 1988). Results of this pilot levee maintenance study are included in the Research Reports section below.

Two of the government documents are national guidelines and therefore, applicable to the Puget Sound Basin. The first document, *Regional Variances to Levee Vegetation Standards, EP 500-1-1,* outlines the regional variance process and factors that should be considered when creating variances (USACE, 2001). Within the document it notes that *water volume, velocity, depth, bank slope, bend curvature, level of protection provided by the levee, and flood history determine flood conditions and help in the establishment of suitable and unsuitable species and veg density.* The second document is entitled *Guidelines for Landscape Planting and Vegetation Management at Floodwalls, Levees, and Embankment Dams,* EM 1110-2-301 (USACE, 2000). It considers appropriate trees, shrubs, vines, and grasses that do not compromise the safety of the structure to be beneficial and states vegetation should be considered in the planning and design process. It goes on to describe the guideline details including information on the vegetation free zone, the root free zone, urban versus rural levee plantings, and site conditions to consider when doing a feasibility analysis for vegetation on levees. It also states that shrubs and small trees may be planted on berms if they are on a section of berm that has been overbuilt so that roots do not penetrate the root free zone (and don't inhibit inspection and flood-fighting), but large shrub masses and woody-type ground cover should be avoided.

#### *ii. Research reports*

The second category of documents consists of reports on research conducted by government agencies relating to vegetation and levees. A few of these only studied grass and didn't address woody vegetation and therefore, are not included in this summary. The remaining documents are summarized below.

In 1967, the Pilot Levee Maintenance study conducted by researchers at the California Department of Water Resources in the Sacramento-San Joaquin Delta, looked at alternative levee maintenance methods that could provide for multiple uses of levees (Davis et al., 1967). They conducted numerous field experiments at five test sites along the Sacramento River to look at vegetation performance and maintenance on levees and revetments as well as studies on levee berms. The erosion control study only looked at grasses while the study on woody vegetation (trees) simply looked at establishment and adaptability to levee conditions. They do, however, conclude that properly maintained native vegetation can be compatible with the flood control function of levees. Their report also provides an illustration for recommended location and spacing of trees on levees with and without a berm.

An investigation was undertaken in 1979, modeling wave attenuation produced by cottonwood trees to provide data that could be used to estimate river channel and levee embankment protection by vegetation (Markel, 1979). The investigator used a wave flume to simulate natural water movement and measured attenuation produced by surrogate trees when water levels were at tree stem level and tree branch level. The results of this study show that wave attenuation by stems maxed at 15% and averaged 9%, while attenuation at branch level maxed at 45% and averaged 15%. They concluded that cottonwood trees were not very effective for levee protection based on these results. However, they noted this study did not include foliage and therefore, these numbers are believed to be on the lower limit of wave attenuation.

A study investigating the levee failures of the spring 2008 Midwest flood was included in the USACE literature review; however I could not obtain the document in digital format from the USACE Engineering Research and Development Center website (only a hardcopy is available at the USACE-ERDC Vicksburg, Mississippi Library). I was able to locate a PowerPoint presentation about this study online and have included some of their concluding remarks obtained directly from one of these slides: it says that *distress and failure of the Pin Oak Levee provided more evidence of the destructive effects on levees by burrowing animals; the two Cap au Gris levee failures, caused by overtopping flows, exposed previously hidden extensive tree root systems within the breaches. There is no evidence that the roots impacted the performance of the levees; removing trees and their root balls without adequately remediating the disturbed ground and extracting the root system appears to have exacerbated the marginal underseepage/seepage conditions at the east St. Louis levee; and large tree roots in the Midwest can penetrate deep into levees, even if they are located more than 15 feet away from the toe of the levee. Many of the existing levee systems in the Midwest, if situated near large trees, are possibly embedded with extensive tree root systems* (USACE).

Jesco Environmental and Geotechnical Services, under the direction of the USACE New Orleans District, gathered data on tree root extent and behavior to provide empirical data to guide future levee vegetation management (USACE, 2009). Data collection focused on tree removal project areas in the greater metropolitan area of New Orleans. After conducting a general literature review, 79 trees were selected for root-profile wall mapping, all of which were located within a corridor from the toe of the levee to a distance where roots might *extend.* They observed that the number of roots greater than 0.5 inches in diameter decreased with distance from the base of the tree.

#### d. Books

In his book, *Bioengineering for land reclamation and conservation*, author Hugo Schiechtl provides an excellent manual for slope and river stabilization using a variety of bioengineering techniques with both live and dead materials (Schiechtl, 1980). Although he doesn't address levees in particular, the techniques in his book would be applicable to flood control facilities.

Gray gives an excellent overview in the introduction of the book, *Vegetation and slopes: Stabilization, protection, and ecology* of vegetative slope stabilization including information about how vegetation influences interception, retardation, restraint and infiltration (Gray, 1995). He describes the positive influences of vegetation such as root reinforcement, buttressing and arching, surcharge, and soil moisture depletion. He also states that the primary negative influence is the external loading that can occur by vegetation, which in turn can lead to uprooting by high winds or currents. However, this external loading is likely more critical for large trees growing on relatively small dams or levees and sometimes, the main component of the overburden weight acts perpendicular to the failure surface and can actually increase stability. This is due to the fact that the levee embankment slopes are generally shallower. Gray also describes how in Germany a common design practice is to include vegetation that is widely spaced along the levee. They use a combination of grasses, reeds and trees with riprap to

retard levee erosion. His recommendations for vegetation as an effective means to reduce stream and levee erosion and scour is to plant dense low shrubs and grasses that have numerous, non-rigid branches and leaves (e.g. willows) that can flow with the force of the water.

#### e. News Articles

All of the LEVVEG news articles in the USACE literature review were released in 2007 or early 2008 and address citizen concerns for implementation of the national levee vegetation standards. In addition, one article written by Matt Weiser for the Sacramento Bee discusses results of a U.C. Davis research study looking at the effect of varying water velocities on willow plant movement (Weiser, 2007). Results show that willows offer little resistance to water flow as they flatten against the ground surface as flows increase. They also found that bent shrubs protect the soil from erosion and create a bottom layer of slower water, which may be used by young salmon seeking refuge. It should be noted that this study was not particular to levees. Official results for this research could not be located for this literature review.

#### f. Proceedings

Of the 12 proceedings coded as LEVVEG, a few of them were presentations of research mentioned elsewhere in this report, and two of them were studies relating to grass and thus, excluded from this summary.

In a presentation given at the August 28$^{th}$, 2007 Vegetation Challenge Symposium in Sacramento, California, Gray describes the factors affecting the stability and integrity of earthen levees. Gray, along with other researchers who made up the Independent Levee Investigation Team (ILIT), set out to determine the failure mechanisms of levees following Hurricane Katrina, including the role of woody vegetation in these failures (Gray, 2007). In their final report they describe three failure mechanisms for levees, mass-stability failures, surficial erosion, and hydraulic forces. Vegetation plays little or no role in the failures and when growing on levees, the roots of woody vegetation reinforce the soil and increase the resistance to shallow, sloughing failures. Their observations in New Orleans showed that the presence or absence of trees on levees had little or no effect on hydraulic gradient-induced seepage failure. The main concern for vegetation on levees is poor maintenance that hinders proper inspection and flood-fighting capabilities.

Daar et al. (1984) described a recommended vegetation management program for levee systems to enhance levee safety, consider environmental concerns, and improve maintenance costs. These recommendations were based on research studies by others and contrast with standard levee maintenance practices. One study mentioned describes vegetation and ground squirrel abundance and notes that ground squirrels prefer barren ground, outcrops or elevated areas with nearby food sources. Traditionally planted levees contain such desirable attributes, and are therefore prime habitat for ground squirrels. He concludes that low-growing broad-leafed plants are a good choice for levees.

Results of a study conducted by Dennis et al. (1984) show that trees with laterally spreading root systems, such as some willow species, provided paths for piping water and that trees with shallow root systems, such as alder, were subject to wind throw. Dense, overgrown vegetation can obscure the levee face from easy visual inspection. However, on levees that have been overbuilt or setback, riparian vegetation planted on the berm can be effective in dissipating energy of flood flows and waves against the main levee.

Carter et al. (1981) presented constraints and opportunities regarding riparian vegetation on flood control levees at a California Riparian Systems Conference on the University of California-Davis campus. He stated that on adequately overbuilt levees, trees and shrubs can remain on the levee slope as long as

spacing requirements and selective removal to maintain access are considered. Unacceptable vegetation is described as any vegetation that provides abundant food supply for rodents, difficult to eradicate, and thorny or intrusive making inspection and maintenance difficult.

Nolan (1981) summarizes concerns regarding levee vegetation dating back to a very old Spanish book and testimonials from various resource agencies in California. He reiterates USACE standards for vegetation on levees denoting the many detrimental effects of certain vegetation to levee integrity. He does say that plantings of willows and other species suitable for the riverside can retard bank erosion, but that large trees on levees are undesirable as they create slipouts due to the superimposed load on the levee.

#### g. International Guidance Documents

The USACE literature review included two international guidance documents outlining guidelines for vegetation on levees, one from the British Columbia Province in Canada and the other from Japan. The Japanese document, *Manual for River Works in Japan*, could not be obtained for this review, nor could the other Japanese documents referenced in the USACE literature review. We were able to obtain the British Columbia document, which outlines the type and size of vegetation that is acceptable for dikes in British Columbia (Ministry of Environment, 1992). The document notes that *vegetation can improve both dike safety and habitat through soil conservation and erosion control.* It goes on to outline the guidelines for dike vegetation, which includes that dike crests, both slopes, and a minimum three meter strip beyond the landside toe shall have no vegetation except trimmed grass. It also states that large vegetation (greater than 300mm diameter) shall be removed from an additional two-meter strip beyond toe on the waterside.

#### h. Reviews

In a review done by Hershey (Hershey et al., 1994), an overview of projects supporting agroforestry along riverbanks and infrastructure is provided. Hershey states that trees in the bottomland of rivers perform many functions such as stabilizing soil and controlling scour erosion, stands of trees absorb the energy from floodwaters and cause the deposition of water borne sediments, and they store the overflow waters and improve water quality and aquatic life.

#### i. Recent Research - 2008 to present

A review of the literature released since 2008 showed only a few research studies pertaining to vegetation on levees including research conducted by the USACE Engineer Research and Development Center and the Sacramento Area Flood Control Agency. In addition, a few European researchers have conducted relevant research and their studies are included in the summaries below.

#### j. U.S. Army Corps of Engineers (USACE) Research

In July 2011, the USACE, Engineer Research and Development Center published a final report of their multi-year effort entitled, *Initial Research into the Effects of Woody Vegetation on Levees* (USACE, 2010). Presented in four volumes totaling over 1200 pages, the report is extensive and includes a project overview (Vol. I), field data (Vol. II), numerical modeling (Vol. III) and a summary of results and conclusions (Vol. IV). The research mostly focused on modeling of single live trees for seepage analysis and slope stability analysis, as well as root characterization and site conditions through field work. Limitations of this study are that it only includes sandy or silty levees, and living, isolated trees. The researchers determine that a tree on or near a levee may increase or decrease the factor of safety, depending on the local conditions such as soil types, levee design, climate, moisture as well as tree species. Field site characterization studies were conducted in four locations in the Western US, including one site in Burlington, Washington. During this study they looked at levee geology, soil

properties around study trees, root structure and root strength. Results indicate that there is no statistically significant difference in average hydraulic conductivity of a soil layer due to tree roots. In addition, root pullout tests show that location and diameter of the root are important, but species of vegetation is not.

USACE also conducted the results from a seepage analysis using the finite element method on the four levees in Sacramento, CA; Burlington, WA; Albuquerque, NM; and Portland, OR (Tracy and Corcoran, 2012). They found that a tree placed on or just below the toe of the levee significantly affected the exit gradient. However, trees placed anywhere else on the levee did not affect the exit gradient.

#### k. California Levee Vegetation Research Program (CLVRP)

The California Levee Vegetation Research Program (CLVRP) was formed in 2009 with the goal of better understanding risk factors associated with vegetation on levees. It is sponsored by seven public agencies to provide data to inform future policy regarding vegetation on levees in the Central Valley. Research project descriptions and results were obtained from the Sacramento Flood Control Agency website (SAFCA, 2013) and from published articles as noted.

##### *i. Tree root architecture in relation to levees (UC Davis)*

The objective of this study is to determine the spatial extent of tree root architecture in relation to levees, to provide a scientific basis for assessment of potential impacts of tree roots on levee integrity and stability. This study looks at root architecture responses in relation to slope, height, aspect, soil texture, etc., as opposed to previously conducted studies that mostly looked at trees growing on flat surfaces. Methods consist of using a pneumatic 'air knife' to excavate of tree root systems of cottonwoods (*Populus fremontii*) and valley oaks (*Quercus lobata*) in combination with T-LiDAR scanning of the soil surface, trees and tree root systems. The research team are investigating spatial distribution of roots and branching. Preliminary results indicate that tree roots do not penetrate deep into the levee, rather they grow parallel along the levee slope at a fairly uniform depth. In addition, the roots systems are shown to be directionally asymmetric when comparing parallel and perpendicular directions to the levee. The information gathered in these field studies will be incorporated into geotechnical models and important parameters critical to the stability of the levee will be computed.

##### *ii. Slurry cut-off walls and roots (HDR, Inc.)*

To investigate if tree roots penetrate slurry walls and to determine their effect on the wall and levee integrity, the researchers excavated trenches around an 18-year-old soil-cement-bentonite (SCB) slurry wall in a Sacramento-area levee. The excavations were completed opposite large black walnut, oak and cottonwood trees to determine root depth, length, penetration into the slurry wall, and variations by tree species. Results show that root growth and interactions with a slurry cut-off wall vary by tree species, but that SCB cutoff wall provided a partial barrier against root penetration. Roots did grow into small cracks in the wall to depths of up to six feet most likely due to the higher moisture content in the SCB wall. Oak trees did not penetrate significantly into the wall, but black cottonwood roots traveled over 80 feet and penetrated the wall at depths of four to ten feet from the levee surface.

##### *iii. Slope stability and roots (UC Berkeley)*

To examine the effects of roots (live and decaying) on levee seepage and slope stability, the researchers conducted a field test to measure the effects of seepage around the decaying roots of a eucalyptus stump on the landside of a levee. They excavated two trenches around the stump and flooded the upslope trench at a constant head to observe and measure resulting seepage in the downslope trench. They compared the results to a set of control trenches constructed away from the stump. During the weeklong flow test, flow patterns were dominated by flow through animal burrows in the levee and that

the last location to saturate during the wetting test was the area behind the stump. Preliminary model simulations appear to be consistent with the field test data.

#### *iv. Tree windthrow and levees (University of Georgia)*

The researchers undertook tree winching to look at the resistance of Central Valley trees to windthrow (Peterson and Claassen, 2012). They successfully completed static winching tests on 66 trees of Valley Oak (*Quercus lobata* Nee*)* and western cottonwood (*Populus fremontii* Wats*)*. Some trees were excluded due to equipment failure, low branching, and in the case of a few smaller trees (>20cm dbh) failure to uproot or break altogether due to extensive deflecting of the stem. Results show that 35 trees uprooted, while the remaining 31 trees had trunk breakage. Trees that uprooted created a mean root pit area of 4.11 m2 and the area of the pit increased with trunk diameter. In addition, they found that uprooted trees are likely to remove a major fraction of the coarse roots from the soil and therefore, would reduce the potential for water seepage caused by exposed root channels. In addition, the study showed a significant trend of the largest size classes being more likely to uproot, however it would take substantial winds to overturn large healthy trees of the species studied.

#### *v. Burrowing mammal habitat associations (UC Davis)*

The objective of this study was to evaluate habitat associations of burrowing mammals on levees in order to assess the effects of vegetation management on these species. Focusing on California ground squirrels, they analyzed habitat associations at different scales (micro, macro and landscape) and found that the occurrence and abundance of squirrels along levees had a strong negative association with tree cover and leaf litter. They also found the same effect for grassland and shrub cover on squirrel abundance, although it was only significant on the land side of the levee. Burrow site selection was influenced by habitat within five meters of the levee; squirrels preferred barren areas and shrub cover and avoided pavement, leaf litter, trees, gravel and riprap.

#### *vi. Mammal burrow dimensions (UC Davis)*

The objective of this research study was to conduct a literature review on the burrow dimensions of mammals, particularly California ground squirrels, to better understand factors that influence those dimensions. The researchers investigated factors potentially influencing burrow dimensions including soil characteristics, age of the burrow, body size and degree of sociality. The literature revealed that length varied greatly among species, ranging from 1.4 meters to 26.1 meters. Depth also varied from 0.2 meters to 1.8 meters depending on the species. Burrow length and depth was positively correlated to body mass and the more social species excavated longer burrow systems. In addition, they concluded that age of the burrow is important, and when California ground squirrels are regularly controlled, burrows were shorter in length. Therefore, if ground squirrel populations persist at high densities over time, longer burrows and more connected burrows may result.

#### *vii. Mammal burrow extents in California Levees (UC Berkeley)*

This study is in progress and results have not been officially released. It is listed on the CLVRP website and so we included it in this report for future reference.

#### *viii. Influence of vegetation on levee past performance (URS Corporation)*

The researchers collected available documents pertaining to non-urban levees in the Central Valley to investigate the influence of vegetation on past levee performance. They systematically reviewed and summarized the data obtained from engineering and construction records, maintenance records and other relevant media (photos, letters, maps, etc.). Of the 10,000+ records they reviewed, a small percentage (1.4% or 95 records) mentioned something about vegetation in the performance record, and

only 11 records total indicated that vegetation influenced levee performance. The remaining 84 records were either inconclusive or indicated vegetation influenced operations and maintenance of the levee.

#### l. Other Recent Research

Dr. Caroline Zanetti led a research study to assess the risks associated with woody vegetation on dikes (levees) by measuring the root system of common tree species and the impact they have on the stability of dikes (Zanetti et. al. 2011). They excavated 108 stumps on seven French dikes with a mechanical shovel and carried out manual measurements on the stumps and root architecture. They found that substrate materials influence root structure where low-density surface and mixed root systems occurred on gravelly material, while thicker, denser roots were found on silty or sandy material. Additionally, three types of roots were identified which included vertical taproot, short slanting root and long horizontal root. They found that locust and poplar have thick, long horizontal roots and poplar also has large, long taproots. These types of roots can have a negative effect on the dike structure when compared to shorter roots.

Lammeranner and his research team tested the effects of small to medium growing, flexible woody plants on structural integrity and maintenance of levees (Lammeranner). They constructed two research levees built to scale in Austria, planting them with different forms of bioengineering techniques using woody vegetation and compared it to a control of turf vegetation. Results of this study are presented in German.

Dr. Ronald Haselsteiner, P.E., Project Engineer at RMD-Consult based in Munich, Germany has been studying the impact of woody vegetation on small embankment dams as well as other areas of flood protection measures, dam and dike design, and water power and geotechnical issues. He has produced articles and given presentations on the subject and was an invited speaker at the 2007 Levee Vegetation Symposium in Sacramento. He presented information about Bavarian/German experiences, design and research regarding woody vegetation on dykes, in particular along the Danube River (Haselsteiner, 2007). He states that historically, there was little woody vegetation along the river and a high discharge capacity of the floodplain. But today there is a marked increase in woody vegetation, which has reduced the floodplain discharge capacity and led to increased water levels and flooding. Because of this, the future vegetation management plan along the Danube River will involve clearing critical existing vegetation to increase discharge in the floodplain.

In another document found during this literature review search, Haselsteiner provides an overview of the topic of woody vegetation on levees (Haselsteiner). This document does not appear to be published or peer-reviewed as it was obtained online with no reference to a publication. However, in this document he outlines the current regulations and mentions the debate that is occurring in the United States regarding woody vegetation. He incorporates findings from other reports or studies that show the connection between woody vegetation and embankment damage noting that "*case studies and experiences with damage caused and/or supported by woody vegetation are numerous*." However, he also notes that many of these damages are due to a lack of maintenance, in part due to overgrown vegetation. This document provides his recommendations for vegetation maintenance on small embankment dams including proposed zonal criteria with drawings, refurbish measures, and removal of woody vegetation.

### 4. Conclusions and Recommendations

A review of the literature has revealed that there are numerous factors, which may positively or negatively affect levee stability and all variables should be looked at within a local geophysical context. The most important factors include the levee size, fill material, slope, location of woody vegetation on the levee itself, where the vegetation is located along the river, vegetation type, size, root architecture ,

rooting depth and tensile strength, as well as hydrologic and hydraulic conditions. A brief summary of these factors is presented below.

River geometry, particularly outside bends, may have an impact on damage susceptibility. Cottonwoods on steep levee slopes were more likely to break off during strong winds than those on flat ground. Location of woody vegetation on a levee is also a factor in slope stability; trees on the upper slope may reduce the factor of safety while trees on the lower slope may increase the factor of safety. Also, on levees that have been overbuilt or setback, riparian vegetation planted on the berm can dissipate energy of flood flows and waves against the main levee. A riparian buffer between the mainstem river and the levee can minimize levee damage risk if the buffer is sufficiently wide.

Trees and shrubs vary in the role they play in slope stability due to differences in stem flexibility, strength, and rooting structure, which should influence the decision about where to use each vegetation type. Trees have been found to be more resistant to windthrow in denser substrates. The distance that tree roots travel varies among tree species, but species is less important than root diameter and location with regards to root pullout stress. Trees and leaf litter have been shown to have a negative effect on the abundance and burrowing activity of ground squirrels and gophers. Mammal holes have been found to provide a more direct flow path than decomposing vegetation and roots.

Recent research conducted on woody vegetation and levee integrity has contributed a considerable amount of knowledge to the literature, but more research is needed on this complex subject, particularly as it pertains to the King County levees. Several research groups and government agencies have recommended a direction for future research. Their suggestions as well as others formulated through this literature review are as follows:

- Research on the performance of levee systems with dead, woody vegetation and decaying roots (large-scale vegetation removal required under the current policy may greatly increase the amount of decaying roots in levees).
- Forensic investigations on the performance of levees following large floods and the role of woody vegetation in that damage. Aerial photography and remote sensing technologies may allow forensic evaluations, yet few studies have been conducted looking at before and after conditions.
- Additional research on the effectiveness of various bioengineering techniques using woody vegetation with respect to levee integrity, particularly in King County and the Puget Sound Basin.
- The effects of trees and roots on other failure mechanisms, such as internal erosion, scour and wind throw.
- The effect of woody vegetation on levee inspection, maintenance and accessibility to the levee.
- The effect of woody vegetation on population density of burrowing mammals in comparison to traditional sod-producing vegetation.

A one-size-fits-all levee vegetation policy for floodplain management is not likely a viable or desirable choice given the local concerns and circumstances, not to mention the dynamic and heterogeneous nature of our nation's rivers and weather. Current blanket standards required of levee sponsors in King County for emergency funding under Public Law 84-99 need to be reassessed based on current science. While public safety is the number one concern for levee management, there may be a desirable balance to strike between levee safety and environmental protection. Future research should focus on site-specific investigations to take into account local differences in geology, hydraulic conditions, levee material, local flora and fauna, and weather patterns, as well as regional environmental and economic

circumstances. The issue of woody vegetation and levee stability remains a hot debate; however, continued research on the subject is helping pave the path to effective collaboration and management amongst levee sponsors, federal agencies and concerned citizens.

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# APPENDIX E: SUN MODEL (BY MARTIN FOX)

King County

# GREEN RIVER, KING COUNTY, WASHINGTON
# SYSTEM WIDE IMPROVEMENT FRAMEWORK (SWIF)

Photo Credit: King County

# ATTACHMENT B:
# GEOMORPHOLOGY TECHNICAL MEMORANDUM

## FINAL

## MAY 2014

# GREEN RIVER SWIF

# CURRENT CONDITIONS REPORT

# GEOMORPHOLOGY TECHNICAL MEMORANDUM

## FINAL

## MAY 2014

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# 1. INTRODUCTION

This technical memorandum summarizes the objectives, methods, and results of the Geomorphology Assessment for the Green River System Wide Improvement Framework (SWIF). The Geomorphology Assessment is one element of the multi-discipline SWIF project focused on evaluating existing levee conditions and informing the assessment of levee vulnerabilities. The primary objective of this memorandum is to qualitatively evaluate current fluvial geomorphic conditions and apply that information as part of the characterization of current levee conditions. Information resulting from this Assessment will inform the development and implementation of capital projects and program recommendations.

In its current state, the lower Green River is confined by levees and/or revetments that extend nearly continuously from the Tukwila through Auburn. The confining structures were originally intended to confine flooding and reduce bank erosion and channel migration as a means of securing land for agricultural purposes; however in doing so they directly altered channel forming processes. Primary alterations included substantially reducing the width of the active flood conveyance corridor. This was accomplished as abandoned channel bends and the connection with floodplain were cut off by confining structures.

The Green River SWIF project area includes Howard A. Hanson Dam (HHD), located at river mile (RM) 64.5 downstream to the upper reaches of the Duwamish River, at approximately RM 5.5 (the Green River becomes the Duwamish River at RM 11). The focal geography of the SWIF is the Lower Green River portion of the watershed, from approximately RM 5 to RM 32. Within the focus area there are approximately 18 miles of levee systems, of which five are PL-84-99 eligible levees between RM 11 and 32 that are a priority project focus.

The Geomorphology Assessment is focused on the Lower Green River priority focus area, extending from RM 32 at the upstream end to RM 11 at the downstream end (Figure 1). The geomorphic characterization and analyses summarized in this memorandum are based on available reports and information provided by King County.

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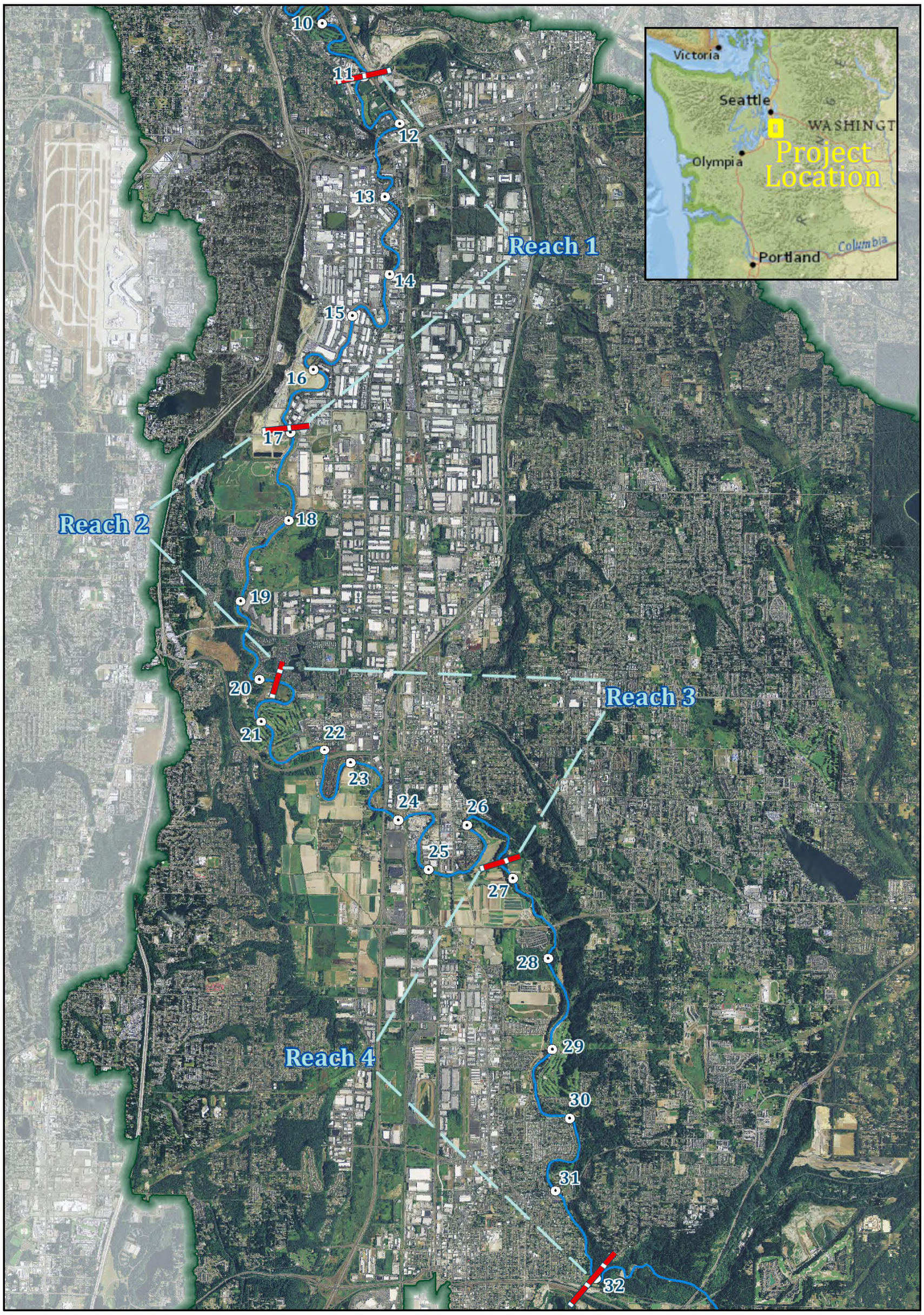


**Figure 1 - Project Location, Reach Boundaries, and River Mile Stationing**

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# 2. Historic Conditions

The modern-day lower Green River has been altered substantially from pre-developed conditions present prior to the mid-1800s. The Duwamish and lower Green River valley, which varies from 6,000 feet to 11,800 feet wide (Collins 2005), was formed during a period of Pleistocene continental glaciation. Melt water streams flowing from several advancing and retreating glacial episodes, collectively scoured the valley bottom to a depth of approximately 500 feet below its current elevation. The valley aggraded to its present level through continuous alluvial and deltaic sedimentation, and episodic lahars (Dunne and Dietrich, 1978, Collins and Montgomery, 2011). Following the full recession of the last glaciation, the Duwamish River conveyed runoff from a network of channels that drained several large subbasins including the Green, White, and Black Rivers, as well as the Cedar and Sammamish Rivers, which flowed into the Black River.

Prior to European settlement in the 1850s the lower Green River was a wide shallow channel that meandered through a relatively low relief alluvial landscape. Except where the channel was positioned against a valley wall by migration, the river was unconfined. The channel migrated actively across the broad valley floor, leaving in its path a network of abandoned channel bends that were reworked by return migration or buried by fine sediment from many frequent flood events (Collins and Sheikh, 2005). The rates at which the river migrated is unknown, however it was likely very slow due to low valley gradients that vary from 0.0002 to 0.0006 (1 to 3 feet per mile). Along with discharge, gradient plays a large role in determining stream power and boundary shear stress, both of which influence the ability of the flow to erode stream beds and banks. These low valley gradients and the sinuous nature of the meandering channel suggest that, if the sediment supply was high, sediment deposition would abound both in the channel and across the flood plain. This likely was the case given that the Duwamish and lower Green are very proximal to Elliott Bay, and that the lower Green River Valleys received water and sediment from the White River, which was known to produce and convey large volumes of sediment. Based on the 1856-1882 General Land Office plat map survey notes referenced in Collins (2005), the elevation of the Lower Green River banks were higher than the surrounding floodplain. The 'banks' were most likely natural river levees formed by sediment deposition when high stage flows overtopped the banks (Collins and Sheikh, 2005).

The arrival of European settlers in the Lower Green River Valley began a long period of modification. From the 1850s to the mid-1900s, the river was channelized, the channel was cleared of wood deposits, the channel banks and floodplain were cleared of natural tree cover, and the flood plain was cultivated, fundamentally altering channel dynamics. Research conducted by Collins and Sheikh (2005) shows clearly that by the early 1900s abandoned channels had been filled in to increase the available area for agriculture; in some places the river may have been diverted from an active channel to one that was abandoned for the same purpose. These activities effectively decreased the width of the active channel corridor, altered the channel alignment and modified channel forming processes.

The Green River basin has been heavily modified over time and its drainage area was substantially reduced as a result of the diversion of the White River and the Cedar/Black Rivers out of the basin in the early 1900s. The floodplain of the White River south of Auburn forms a large alluvial fan deposit defining a low divide between the Green and Puyallup River basins. In 1906, a major flood created a log jam on the northerly margins of this fan and temporarily diverted the White River into the Puyallup River; in 1911 the White River was permanently diverted to reduce flooding near Auburn. Between 1912 and

1916, the Cedar River was also diverted, into the Lake Washington system, to provide water to operate the newly constructed Hiram Chittenden Locks. This eliminated most flow from the Black River.

The routing of the White River away from the Green River decreased the flood hazard but did not eliminate it, and increasing development advanced a period of aggressive levee building along the lower Green River throughout the early to mid-1900s. The HHD, authorized in 1950 for the principal purpose of flood control, was constructed between 1958 and 1962. By the end of the 1960s County-constructed levees were in place and the HHD was in operation. Levees were placed on one or both sides of the river in its then-existing pattern. The combined functions of the Dam and levees effectively reduced the frequency of valley flooding; however, the levees confined the remaining flows, thus increasing their stage at any given flood discharge. In addition, though the dam decreased flood peaks, it spread the duration of flood discharges out over time, including the duration of bank full flows. The HHD also trapped sediment and prevented it from moving farther downstream. The combined effects of these actions, channelization and sediment retention, include higher stream power and boundary shear stress and sediment starvation, all of which enable stream flow to erode channel boundaries. For the channelized sections of the Green River, these conditions have result in in a lowering of the stream bed elevation (incision) and simplification of the channel form. . The absence of tree and understory riparian vegetative cover also likely contributed to erosion along channel banks, which was addressed initially by driven pilings with timber lagging at the base of the levee slopes, and with the placement of rock armor structures on the embankments, and at the toe of the slopes from the 1960s through the present.

# 3. Methods and Evaluations

## 3.1. Introduction

The current condition of the river channel within the focus area is a direct result of the many alterations described in Chapter 1. The channel is confined by levees and revetments throughout most of the focus area. Consequently, most channel sections throughout the lower and middle portions of the Lower Green River focus area are roughly trapezoidal, with simplified channel geometries and generally consistent bank full widths that increase only slightly in the downstream direction.

This chapter describes the methods and materials used in the geomorphic evaluation. Given that the following descriptions are given in terms of channel sinuosity, bank full width, gradient, streambed incision, and bank erosion, the latter of which is accounted for by the repair record for levee and revetment damages from storm events.

## 3.2. Methods

This assessment is based on data and information presented in available studies, reports and maps provided by King County and members of the Tetra Tech project team. All literature and map information are listed in the References section of this Technical Memorandum.

Geomorphic reaches were delineated based on the following factors and considerations:

- Levee System – reach delineations were extended to include named levees.

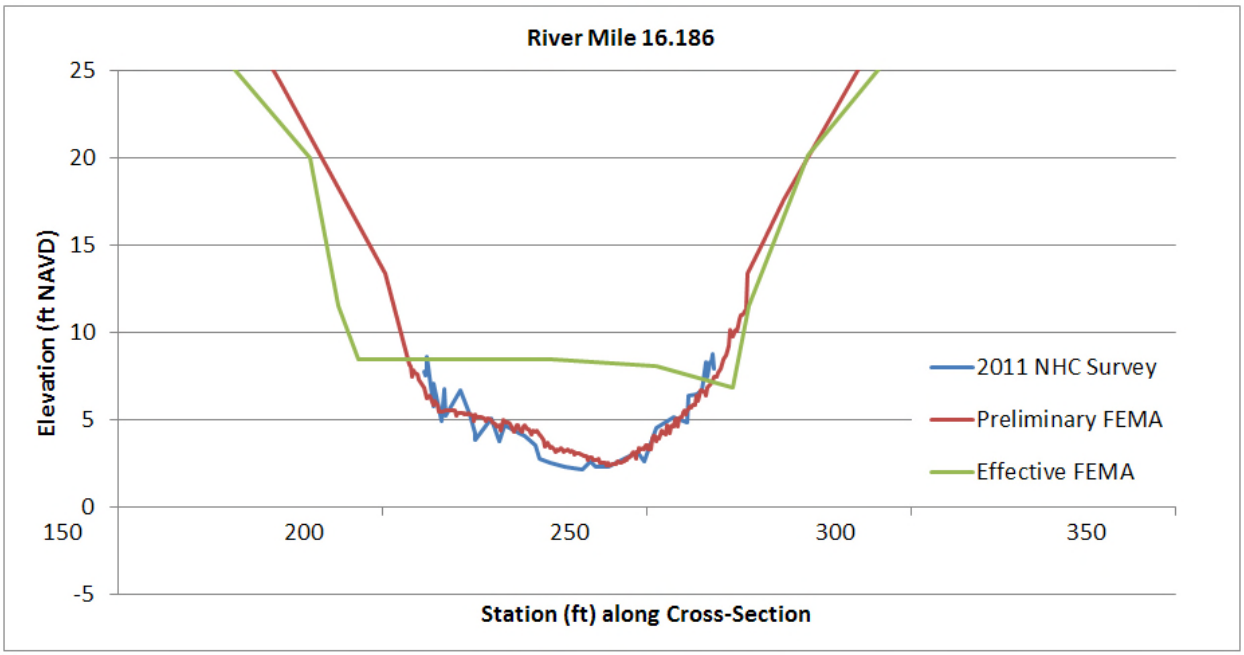
- Channel pattern – primarily based on the sinuosity and geometric form reflected by channel bends.
- Channel gradient – as described in existing reports and depicted in hydraulic modeling studies.
- Reach boundaries delineated by Perkins (1993).
- Location of damages to levees and revetments as reported by King County.

Channel pattern, sinuosity and potential channel migration were derived from evaluation of time series aerial photographs date from 1990 to 2013. This time period was used because 1) the focus area has been confined in place by maintained levees and revetment since the mid-1960s and only negligible changes in channel form and location have occurred since then, 2) the scope of this project is to identify potential levee damage sites under current and existing conditions, and 3) the aerial photographs are readily available from the Google Earth website. The aerial photographs were also reviewed for recent changes in channel character, the presence of road and rail bed revetments, levee structure, and the presence of any features such as large woody debris that may have deflected flow towards or away from a damaged portion of a levee or revetment. The 2013 Google Earth aerial photograph was also used to measure channel and valley lengths for calculating sinuosity.

Stream bed incision was estimated by comparing surveyed channel cross sections used in two FEMA Flood Studies dated 1986 and 2006. Cross sections from a 2011 flood study conducted by Northwest Hydraulic Consultants were also used; this study covered most of the project area from RM 13.5 to RM 32. Examples of the compiled 1986, 2006 and 2011 are shown in Figure 2.

Channel bathymetry, survey by the Muckleshoot Indian Tribe, was also reviewed for the purpose of assessing more continuous stream bed conditions than flood model cross sections can offer. The date of the bathymetric survey is unclear at the time of this evaluation, and could not be used in the scour depth assessment.

Levee and revetment damages from storms and subsequent repairs were extracted from a master list provided by King County. All sites were plotted by RM station on reach maps. The list of damage sites is provided in the 'Levee/Revetment Damage Repair Sites' (Table 1).



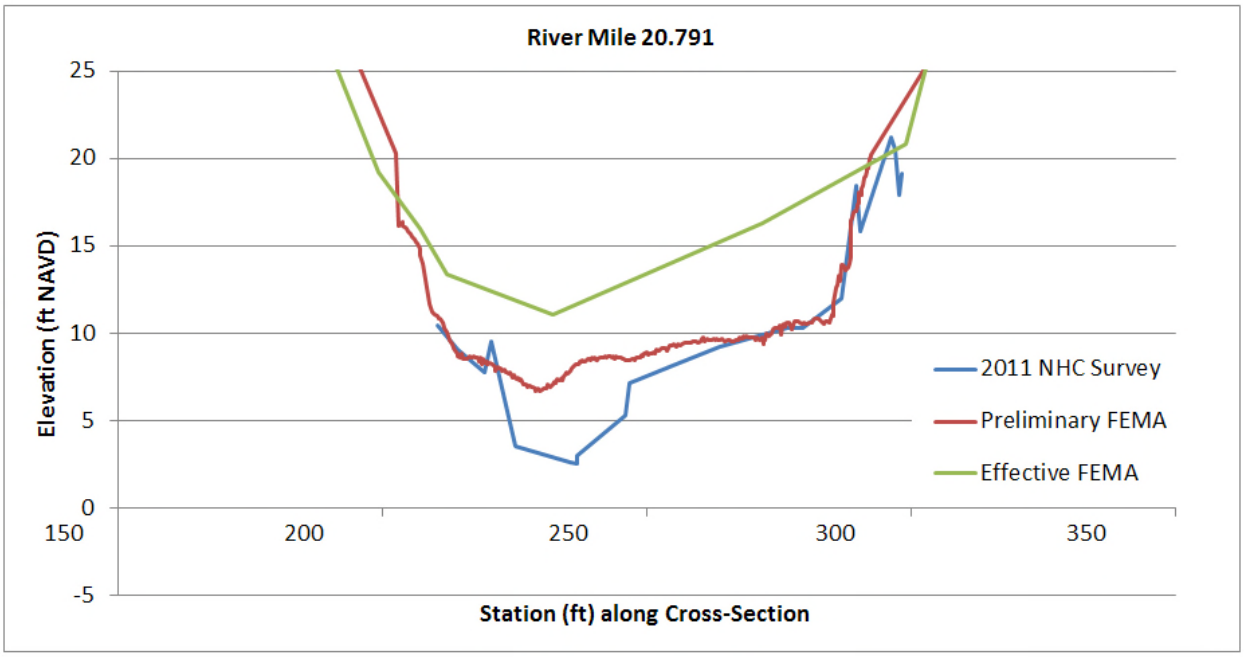




**Figure 2 - Example Flood Model Cross Sections**

**Table 1 - Levee/Revetment Damage Repair Sites**

| Repair Project Name | Levee/ Revetment | Year Damage Occurred | Repair Year | Bank | RM (d/s) | RM (u/s) | Appr. LF |
|---|---|---|---|---|---|---|---|
| Van Warden | Levee | Nov 1990 flood | 1990 | Left | 13.70 | 13.80 | 420 |
| NC Machinery/Liston | Revetment | Nov 1990 flood | 1991 | Right | 13.70 | 13.77 | 370 |
| Christiansen Trail (a.k.a. F&N warehouse) | Levee | Nov 1990 flood | 1992 | Left | 14.15 | 14.21 | 210 |
| Home Depot (Tuk. 205) | Levee | Nov 1995 & Feb 1996 floods | 1996 | Left | 14.21 | 14.26 | 265 |
| Tukw ila 3 (U/S from S. 180th St.) | Levee | Jan 2006 flood | 2008 | Left | 14.37 | 14.57 | 1055 |
| Tukw ila 5 (part of Segale) | Levee | Jan 2006 flood | 2008 | Left | 14.90 | 15.10 | 1055 |
| Ratolo/ Segale Riverward Corps Repair | Levee | Nov 1990 flood | 1991 | Left | 15.10 | 15.16 | 265 |
| Desimone Levee - Toe Repair | Levee | Nov 1995 & Feb 1996 floods | 2002 | Right | 15.10 | 15.45 | 1320 |
| Segale Levee - Toe Repair | Levee | Nov 1999 flood | 2003 | Left | 15.16 | 15.20 | 200 |
| Segale Riverward Levee | Levee | Chronic toe and bank instability, oversteepened slope | 1995 | Left | 15.16 | 15.40 | 900 |
| Desimone - Levee Setback | Levee | Nov 1995 & Feb 1996 floods | 1998 | Right | 15.10 | 15.40 | 1060 |
| Desimone - Levee Setback | Levee | Nov 1995 & Feb 1996 floods | 1999 | Right | 15.40 | 15.45 | 265 |
| Briscoe School Levee Repair | Levee | Jan 2006 flood | 2009 | Right | 16.33 | 16.44 | 525 |
| Tukwila South at Frager Lowest | Levee | | 2013 | Left | 16.75 | 16.83 | 400 |
| Tukwila South at O'Connell | Levee | | 2013 | Left | 17.13 | 17.28 | 800 |
| Christian Brothers | Levee | Nov 1995 & Feb 1996 floods | 1998 | Right | 17.02 | 17.12 | 530 |
| Boeing RM 17.62 | Revetment | Nov 1995 & Feb 1996 floods | 1998 | Right | 17.65 | 17.68 | 155 |
| Boeing RM 17.80 | Revetment | Nov 1995 & Feb 1996 floods | 1996 | Right | 17.75 | 17.76 | 55 |
| Boeing RM 17.74 | Revetment | Nov 1990 flood | 1991 | Right | 17.76 | 17.77 | 90 |
| Russell Road | Revetment | Nov 1995 & Feb 1996 floods | 1998 | Right | 17.90 | 17.92 | 100 |
| Russell Road Lowest | Revetment | Nov 1995 & Feb 1996 floods | 1997 | Right | 17.95 | 17.97 | 105 |
| Russell Road Lower | Revetment | Nov 1995 & Feb 1996 floods | 1998 | Right | 18.76 | 18.79 | 865 |
| Russell Road Lower | Revetment | Nov 1995 & Feb 1996 floods | 1998 | Right | 18.9 | 18.95 | 275 |
| Russell Road Lower | Revetment | Nov 1995 & Feb 1996 floods | 1998 | Right | 19.2 | 19.26 | 300 |
| Stoneway Lower Repair | Revetment | Jan 2009 flood | 2009 | Left | 19.43 | 19.46 | 210 |
| Russell Road Upper | Revetment | Nov 1995 & Feb 1996 floods | 1998 | Right | 20.31 | 20.39 | 550 |
| Kent Shops -- Narita | Levee | Jan 2006 flood | 2008 | Right | 20.40 | 21.08 | 1600 |

| Repair Project Name | Levee/ Revetment | Year Damage Occurred | Repair Year | Bank | RM (d/s) | RM (u/s) | Appr. LF |
|---|---|---|---|---|---|---|---|
| Levee | | | | | | | |
| Narita | Levee | Nov 1995 & Feb 1996 floods | 1999 | Right | 21.08 | 21.17 | 500 |
| Myer's Golf Levee | Levee | Jan 2006 flood | 2008 | Right | 21.50 | 21.80 | 1400 |
| Pipeline Levee - Toe Repair | Levee | Nov 1995 & Feb 1996 floods | 2002 | Right | 21.84 | 21.91 | 600 |
| Narita Levee - Toe Repair | Levee | Nov 1995 & Feb 1996 floods | 2003 | Right | 21.08 | 21.17 | 500 |
| Pipeline | Revetment | Nov 1995 & Feb 1996 floods | 1999 | Right | 21.84 | 21.91 | 600 |
| Okimoto | Levee | Nov 1990 flood | 1993 | Right | 21.91 | 22.00 | 585 |
| Signature Pointe Lower | Revetment | Nov 1995 & Feb 1996 floods | 1996 | Right | 22.19 | 22.28 | 320 |
| SignaturePointe Upper | Revetment | Nov 1995 & Feb 1996 floods | 1997 | Right | 22.62 | 22.75 | 600 |
| McCoy Breda | Levee | Nov 1995 & Feb 1996 floods | 1996 | Right | 24.40 | 24.80 | 1800 |
| Breda Levee Setback | Levee | Jan 2006 Flood | 2006 | Right | 24.75 | 25.09 | 1800 |
| Horseshoe Bend Site 4 | Levee | | 2009 | Right | 24.79 | 25.01 | 1040 |
| 78th Avenue South | Revetment | Nov 1990 flood | 1991 | Left | 24.86 | 24.87 | 50 |
| Plemmons | Levee | Nov 1995 & Feb 1996 floods | 1996 | Right | 25.17 | 25.21 | 200 |
| Horseshoe Bend Site 3 | Levee | | 2009 | Right | 25.20 | 25.22 | 100 |
| Plemmons U/S | Levee | Nov 1990 flood | 1994 | Right | 25.28 | 25.32 | 210 |
| Horseshoe Bend Site 2 | Levee | | 2009 | Right | 25.50 | 25.55 | 160 |
| Nursing Home | Levee | Feb 1996 Flood | 1996 | Right | 25.55 | 25.61 | 200 |
| Horseshoe Bend Site 5 | Levee | | 2009 | Right | 25.97 | 26.03 | 150 |
| Horseshoe Bend Site 1 | Levee | | 2009 | Right | 25.79 | 25.97 | 1140 |
| Nursing Home | Levee | Nov 1990 flood | 1991 | Right | 26.08 | 26.11 | 125 |
| Galli's Section | Revetment | Jan 2006 flood | 2008 | Left | 29.50 | 29.70 | 1110 |
| PL 87-99 Levee Rehabilitation, Dykstra | Revetment | Jan 2006 flood | 2008 | Left | 30.02 | 30.14 | 375 |
| Dykstra/Lone's Addition | Levee | Nov 1990 flood | 1994 | Left | 30.50 | 30.80 | 480 |
| Lone's 3rd Addition | Levee | Nov 1990 flood | 1992 | Left | 30.80 | 30.85 | 320 |

## 3.3. Evaluation in Support of Levee Damage Locations

From a geomorphologic perspective, damage and potential failures along focus area levees and revetments are most likely caused by streambed scour and bank erosion occurring as shallow vertical slump failures along embankment slopes due to the combined weight of mid-slope sediment deposits and flood-related saturation (Andy Levesque; 2014 personal communication). Slumping failures appear to be related either to intermediate seepage or to rapid drawdown conditions following extended periods of higher flows released from the HHD (Levesque, 2014 personal communication). Vertical erosion is not included in this assessment.

The method used to assess potential bed scour sites included evaluation of time series aerial photographs available on the Google Earth website, and review and comparison of channel cross

sections and channel thalweg elevations derived from hydraulic modeling. The aerial photographs reviewed included those dated 1986, 1990, 2002, 2003, 2004, 2005, 2006, 2009, 2010, 2011 and 2012. The hydraulic model cross sections were surveyed for use in three different flood studies dated 1986, 2006 and 2011; the cross sections from each flood study were positioned at the same, or nearly the same, river mile stations.

Comparison of the time series aerial photographs and cross sections indicates whether the channel banks and bottom changed appreciably over the periods of record. Particularly useful to identifying the locations of potential levee failure sites is the comparison of channel cross sections and channel thalweg elevations. The comparative evaluation is based on the premise that vertical changes in the elevation of the channel floor indicate aggradation of the streambed due to sediment deposition, or a decrease due to erosional bed scour. Comparisons of Briscoe-Desimone Reach cross sections (NHC, 2011) show the channel floor elevation has either remained about the same or it decreased over the survey period, and that channel width has changes little if at all. The incision and lack of channel widening are likely attributable to the presence of levees and revetments, and the narrow confines of the channel.

The comparison of the thalweg elevation data shows a decrease in the elevation of the thalweg throughout the geomorphic focus area from 1986 to 2011. Aerial photographs were reviewed for, but provided no visual evidence of local aggradation, such as sustained and/or growing mid-channel or point bars in between cross section locations. The results of these two assessments indicate that aggradation has not taken place since at least 1986 and that the dominant process acting on the stream bed is channel incision.

Streambed scour poses a potentially significant risk of undermining the toes of levees and revetments, which can cause unraveling of levee/revetment materials. Potential levee sites subject to failure due to streambed scour were evaluated using the comparison of channel cross sections. For the evaluation, cross sections from 1986 and 2011 were used to identify river mile stations where the bed elevation decreased five feet or greater. Five feet was selected as the threshold value because it is sufficiently deep to intercept most of the lower Green River levees. The principle results of this evaluation are shown on Figure 3, 'Significant Incision Point Location Map'.

Review of the channel bathymetry provided by the Muckleshoot Indian Tribe indicated the presence of many scour pools along the channel floor. The majority of the pools are situated along the outside banks of bends. The locations of the deep pools shown by the bathymetric map were compared to thalweg scour sites derived from flood model cross section to determine how well the two data sets correlate with one another. The comparison indicates the two sets cannot be used together without considerable calibration. Consequently, the bathymetric data set was not used in the scour assessment.

Results of the cross section/thalweg elevation assessment were also compared against levee and revetment damage sites derived from the Green River Repair Sites Master List, 2013, provided in the King County Levee Retrospective Report. The findings of this comparison are presented in the following sections.

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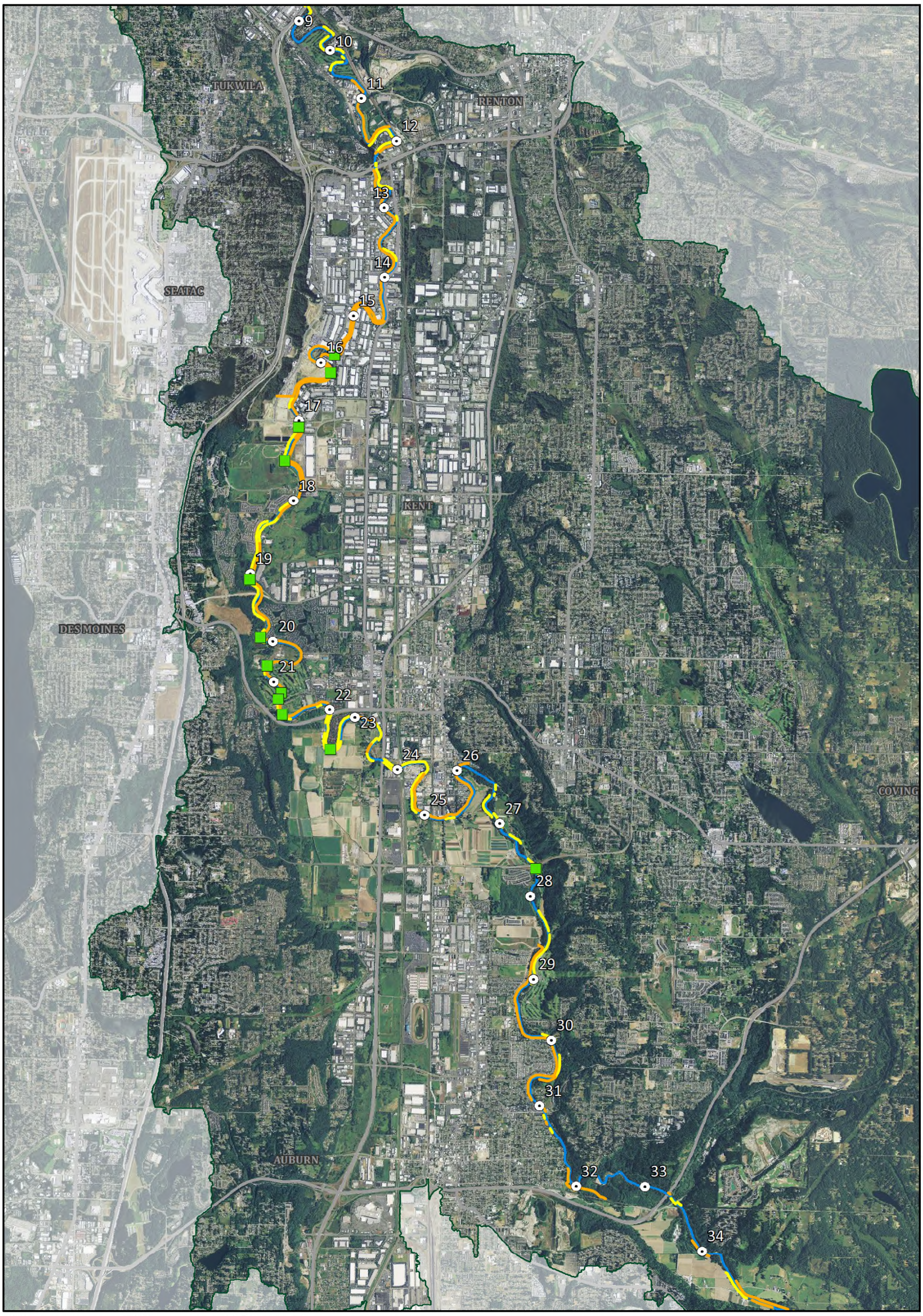


**Green River SWIF**

Significant Incision Point Locations

**Data Sources:** King County-2014, USDA - 2014

N

0 2

Miles

King County

May 2014

Incision Points

River Mile

Levees

Revetments

Watershed Boundary

Green River

**Figure 3 - Significant Incision Point Locations Map**

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# 4. Existing Conditions

## 4.1. Geomorphic Reach Descriptions

For this assessment, the river channel from RM 11 to RM 32 project area was divided into four geomorphic reaches. The reaches are labeled 1 through 4 with Reach 1 located at the downstream end of the project area; the descriptions are presented from downstream Reach 1 to upstream Reach 4. The location and extent of the 4 reaches is displayed on the 'Project Location, Reach boundaries and River Mile Stationing Map, (Figure 1).

For each reach, Google Earth aerial photographs dated from 1990 to 2013 were reviewed to identify changes in channel location and to observe recorded damage sites along levees and revetments. Changes in channel condition and location were observed in Reach 4; no changes in channel location or character were observed in Reaches 1, 2 or 3. The review was successful in identifying repaired confining structures, however, the source of the damage was typically not apparent from review of aerial photographs preceding the repair. Subsequently, no information regarding observed levee conditions or damages leading to a repair are included in the following reach description.

### 4.1.1. Reach 1 -- RM 11 TO RM 16.99

The geomorphologic reach encompasses the Tukwila 205 Levee System, which extends along the left river bank from (RM 12.44 to RM 16.7), and the Desimone - Briscoe School Levee, which is part of Levee System 2, extending along the right river bank from (RM 14.5 to RM 16.99). The primary factors considered in delineating the geomorphologic reach are the sinuosity of the channel pattern and valley gradient; the sinuosity is 1.6 and the valley gradient varies from 0.0002 to 0.0003 (Collins and Sheikh, 2005).

The land adjacent to this reach is heavily developed for commercial and industrial use. Major highways crossing the river include Interurban Ave S, Interstate 405 (I- 405), S. 178$^{th}$ Street, and S. 200th Street. The eastern ends of river bends are in direct contact with the Burlington Northern – Santa Fe railroad, the West Valley Highway and the Green River Trail. The west side of the channel is bounded by Interurban Ave, the Green River Train and short sections of surface streets. Based on our review of aerial photographs the major roads, the railroad grade and the Green Trail appear to be leveed and/or revetted. These structures have successfully held the channel in place and prevented migration from occurring for the last 24 years. The absence of migration likely extends back to mid-1960s, when both the levees and HHD were completed and operational.

Based on a review of the Levee Systems map provided by King County, one or both banks throughout the entire reach are contained by levees, except for one section. The unconfined section is roughly a quarter mile long and is located downstream of the I-405 river crossing (in the vicinity of RM 12.4) where neither bank is leveed. The confining structures yield a relatively consistent bank full width that varies from roughly 150 to 200 feet, with minimum and maximum measurements of 130 and 240 feet, respectively.

Review of surveyed channel cross sections and thalweg elevations show that the elevation of the river bed has decreased over the past 25 years. Comparison of channel thalweg elevations from the 1986 and 2011 channel cross sections indicate the channel locations where incision greater than 0.5 feet has

occurred (Figure 4). The longitudinal thalweg profile is provided in Figure 5 for context and reference purposes. Two groupings of cross sections have been subject to substantial bed degradation. From RM 12.5 to RM 13.22 incision is greater than 3 feet, and from RM 15.24 to $M 16.18, incision is greater than 4 feet. The greatest incision (6.9 feet) occurs around a tight hair pin channel bend at RM 15.85. A scour depth of this nature is common in tight bends such as this, and wouldn't typically warrant much attention. However, the current depth of scour could undermine the toe of the levee and eventually cause a failure. This site is shown on Figure 3, the 'Significant Incision Point Location Map'.

Evaluation of levee and revetment damage sites, where repairs were made from 1990 to 2013, indicates that many of the damage sites are typically located in the immediate vicinities of channel bends (Figure 6), and that their occurrence is related to storms. However, no significant damage sites were recorded in the downstream thalweg incision area extending from RM 11 to RM 13.5. In contrast, the majority of recorded damage repair sites are located within the thalweg incision area just downstream of the hair pin bend RM 15.85. From RM 15.10 and RM 15.50, seven damage sites have a record of repairs from 1990 and 1996 flood events, including at least one toe repair resulting from bank instability and slope over-steepening; this particular area lies adjacent to incision slightly greater than 2 feet.

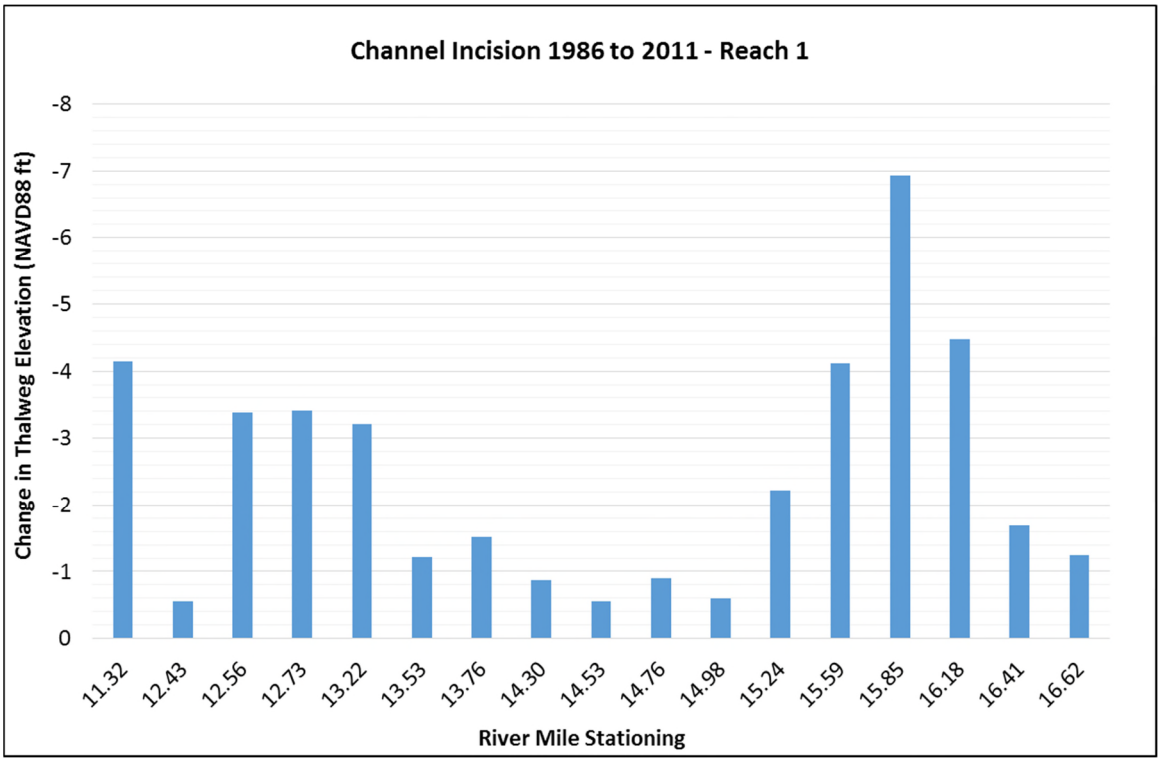


**Figure 4 - Incision Depth Bar Chart - Reach 1**

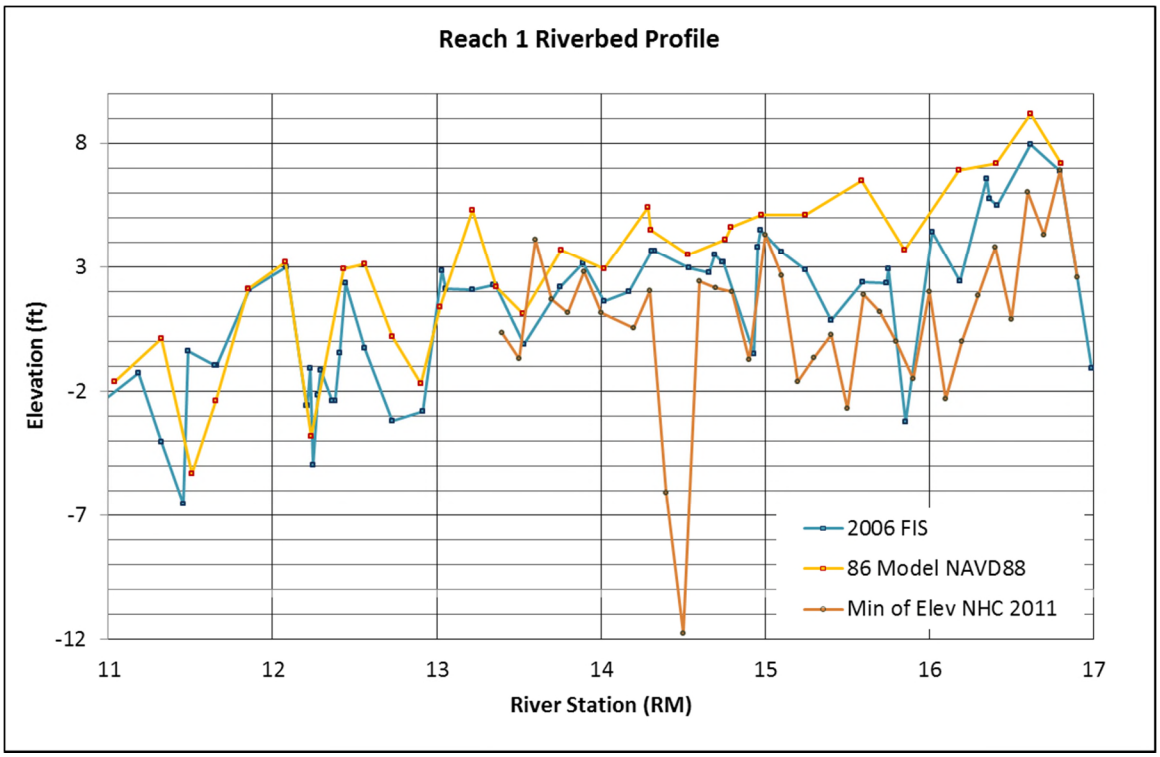


**Figure 5 - Longitudinal Thalweg Profile - Reach 1**

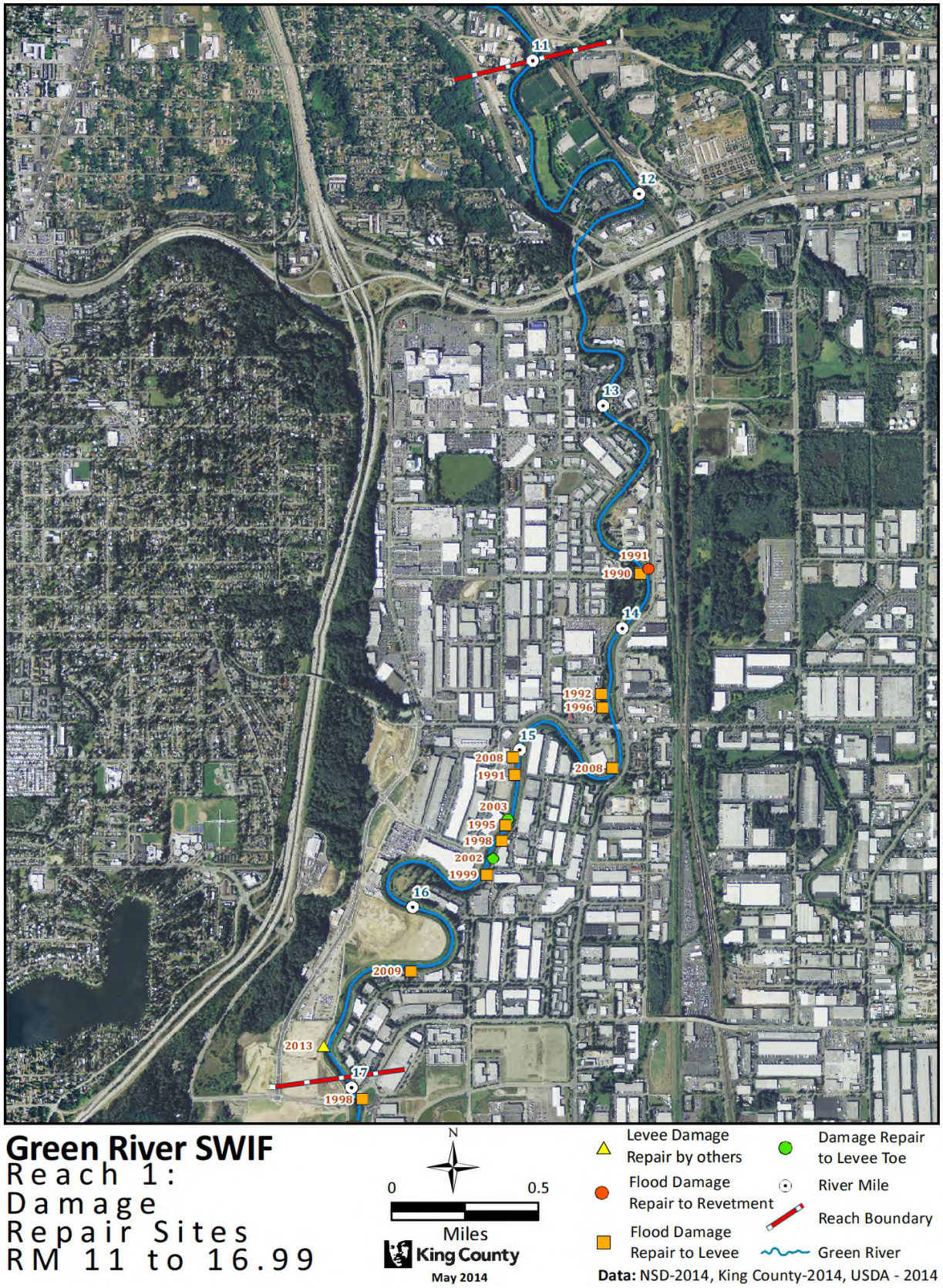


**Figure 6 - Reach 1 Damage Repair Sites**

### 4.1.2. REACH 2 -- RM 16.99 TO RM 20.35

This geomorphologic reach encompasses the full extent of two right bank levees currently eligible for federal assistance in the PL 84-99 Rehabilitation Inspection Program, located in Levee System 2; Boeing (RM 16.99 to RM 17.83), Lower Russell – Holiday Kennel (RM 18.28 to RM 19.28), and the Upper Russell – Soames Dolan Levee System along the right bank (RM19.27 – RM 20.35). The channel is situated near the left valley wall, and is generally characterized by a relatively low sinuosity of 1.2, and valley gradient of roughly 0.00035.

Development within this geomorphic river reach is a mixture of agriculture/horse pasture, park lands, residential subdivisions and commercial. Major roads crossing the river are S. 212$^{th}$ Street and Veterans Drive. The east side of the river is bounded by Green River Trail and Russell Road. Frager Road South bounds the west side of the river. Based on a review of aerial photographs the major roads, and the Green Trail appear to be leveed and/or revetted.

Throughout this reach, levee and road/trail revetments appear present on one or both sides of the river, and are present along the banks of all outside bends. These structures have successfully held the channel in place and prevented migration from occurring for the last 24 years. The absence of migration likely extends back to mid-1960s. Bank full widths vary from 150 feet to 180 feet, with local minimum and maximum measurements of 120 and 210, respectively.

Review of surveyed channel cross sections and thalweg elevations show that throughout Reach 2, the elevation of the river bed has decreased from 1 to 2 feet. As in the case of Reach 1, comparison of channel thalweg elevations from 1986 and 2011 channel cross sections indicates that thalweg incision is typically greater in the immediate vicinities of channel bends. As shown on Figure 7 the deepest recent incision recorded within the reach is located at RM 17.00 (9.2 feet) and at RM 19.07 (5 feet); both of these sites are situated roughly two-thirds of the way around the bends (Figure 6), where the flow velocity against the outside bank is typically highest. The longitudinal thalweg profile is provided in Figure 8 for context and reference purposes.

Review of plotted levee and revetment damage sites indicates that virtually all the damage repair sites related to storms are situated within the apex areas of bends, or where the fastest flow velocities entering a bend impinge upon the levee or revetment (Figure 9). The recorded damage repair sites appear to be distributed evenly throughout the reach; damage repair sites are located in the general vicinity of RM 17.00, where the greatest incision is recorded, but not in the vicinity of RM 19.07 where incision of 5 feet is documented.

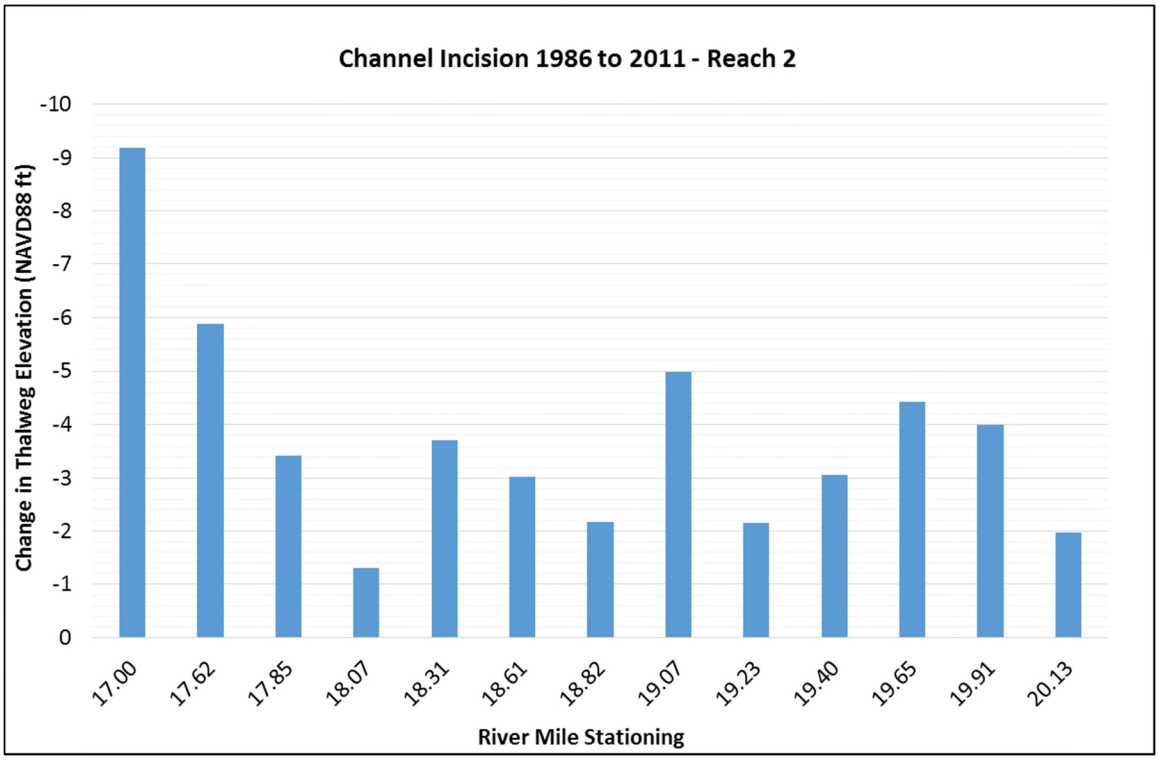


**Figure 7 - Incision Depth Bar Chart - Reach 2**

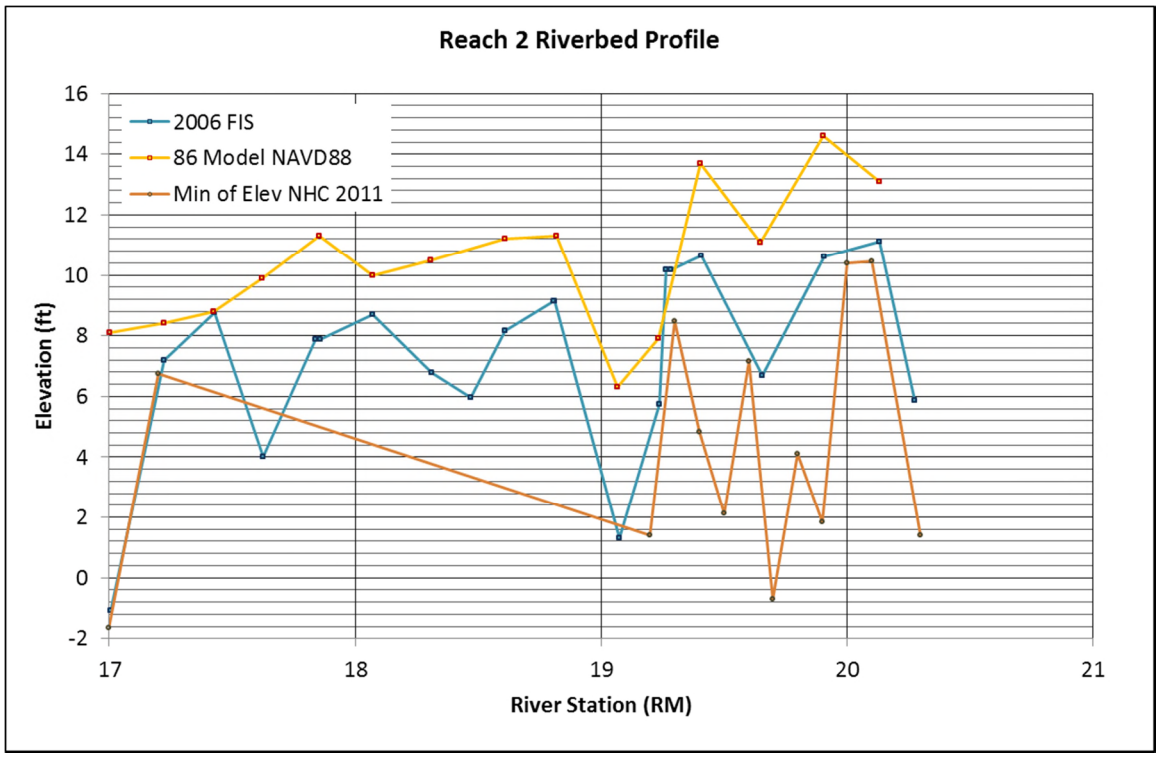


**Figure 8 - Longitudinal Thalweg Profile - Reach 2**

**Figure 9 - Reach 2 Damage Repair Sites**

### 4.1.3. Reach 3 – River Mile 20.35 to 26.8

Reach 3 encompasses the upper portion of right bank Levee System 2 the full extent of Levee Systems 3 and 4. Levees included in System 2 are the Kent Shops - Narita (RM 20.35 – 21.26), Meyers Golf Levees (RM 21.3 – RM 22.04). Levee System 3 Signature Point, extends from RM 22.77 to RM 23.18, and Levee System 4, Horseshoe Bend, extends from RM 24.25 to RM 26.09. The river is characterized by a relatively high sinuosity of 2.8, which reflects the presence of large radius bends and a valley gradient of 0.0003.

Land use throughout this reach is a mixture of agricultural/rural, urban development (Signature Point), commercial and recreational (Riverbend Golf Complex). Major roads crossing the river are W. Meeker Street, SR 516, S. Valley Highway N. SR 167, Interurban Trail, two Burlington Northern – Santa Fe rail lines, and 83rd Avenue S. The north and east side of the river is bounded by the Green River trail and relatively short section of residential surface streets. The west and south side of the river is bounded by Frager Road S., 78th Avenue S., S. 269th Street, S. 269th Place, and short frontage roads. Based on our review of aerial photographs roads and the Green Trail appear to be leveed and/or well revetted. These structures have successfully held the channel in place and prevented migration from occurring for the last 24 years.

As described above, levees are present on the right bank; the left bank appears to be confined in part by revetments, which are largely associated with road embankments. Only two bank sections, RM 23.8 and RM 26.2 to RM 26.7 appear unprotected by levees. Except for channel bends at Horseshoe Bend (RM 24.5 – RM 26), the outside banks of bends appear to be well confined by levees and/or revetments. Bank full widths throughout this reach vary only slightly from 130 feet to 180 feet, with minimum and maximum widths of approximately 110 and 200, respectively.

Comparison of surveyed channel cross sections and thalweg elevations indicate that the channel thalweg elevation has decreased from at least 1 to 2 feet in every surveyed location over the entire reach between 1986 and 2011. The cross sections show the deepest incision has occurred around the apex area of the bends. With the exception of the most upstream bend in the reach at RM 26.10, which has incised about 1 foot, all bends in the reach record thalweg incision of 2 feet or greater (Figure 10); the longitudinal thalweg profile is provided in Figure 11 for context and reference purposes. The deepest incision is recorded around bends at RM 21.14 (nearly 7 feet), RM 22.50 (5.2 feet), and from RM 23.47 through RM 24.50 (3.4 to 3.7 feet), this last grouping encompasses Horseshoe Bend. Incision greater than 5 feet deep is shown (Figure 3).

Review of plotted levee and revetment damage sites (Figure 12) indicates that most damage repair sites related to storms are again situated along the apex areas of bends, and where the stream flow impinges upon the levee or revetment as it enters the bend or is deflected by the channel alignment. The recorded damage repair sites tend to be located along channel sections where incision has occurred.

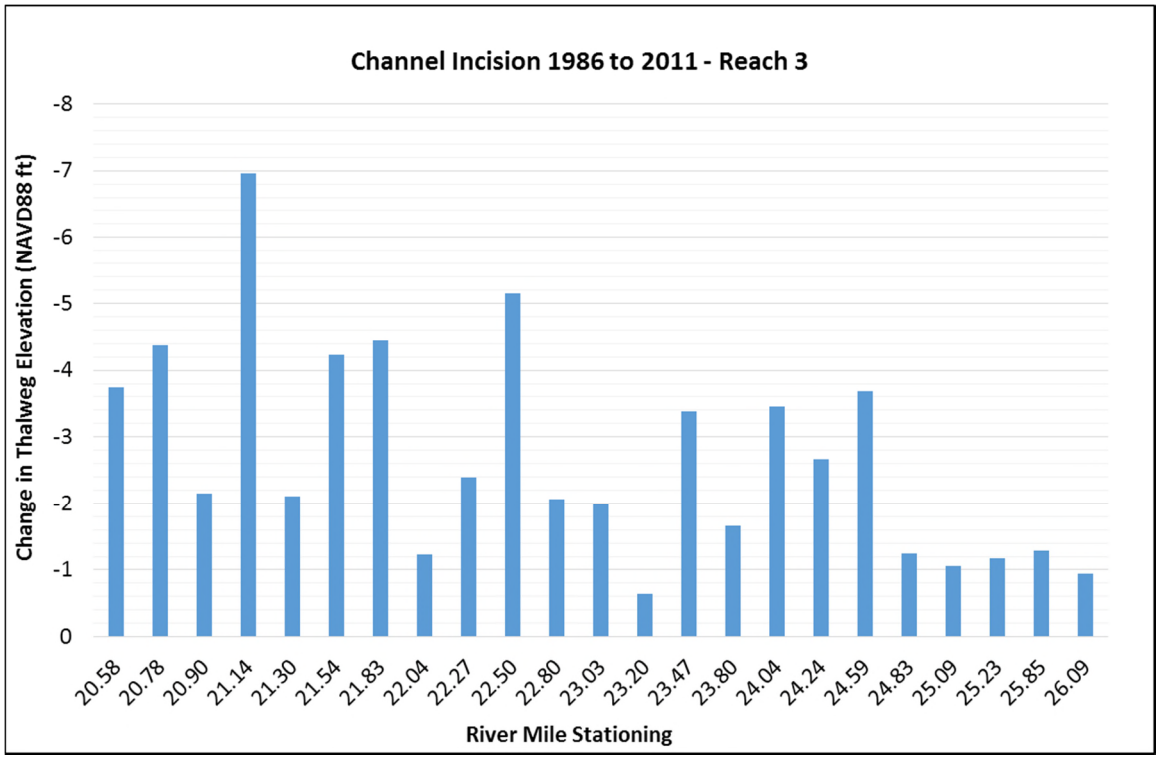


**Figure 10 - Incision Depth Bar Chart - Reaches 3**

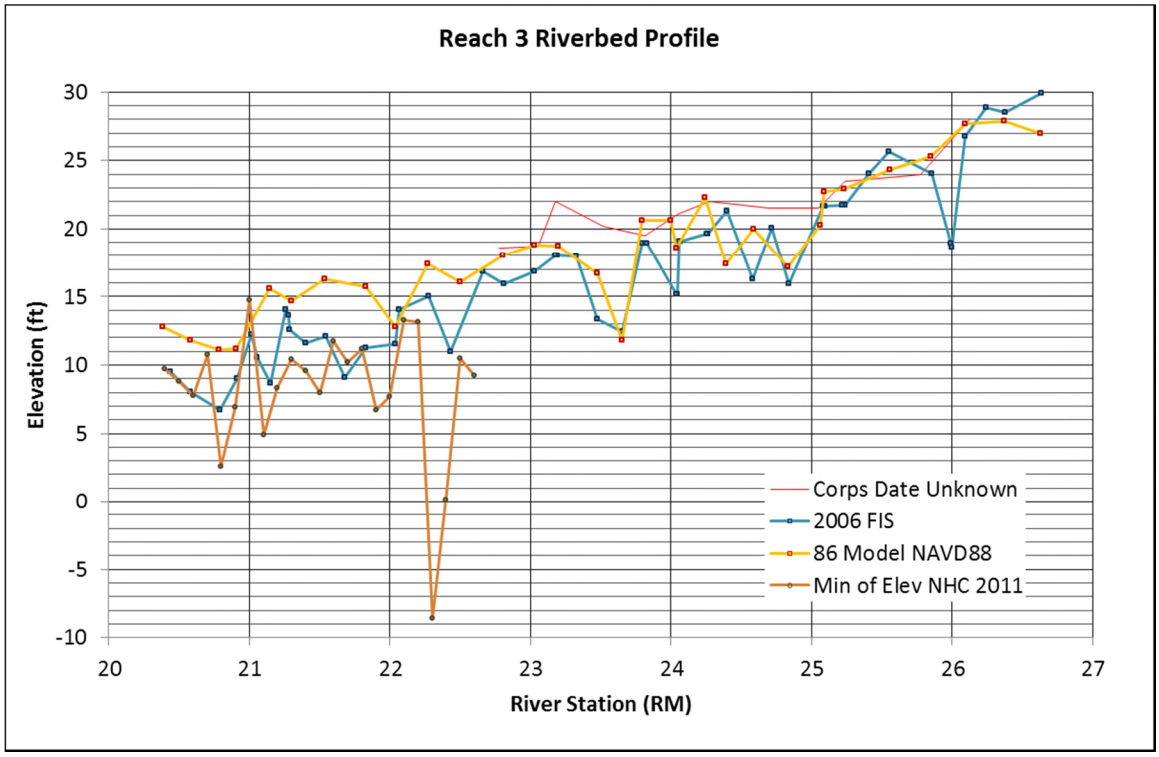


**Figure 11 - Longitudinal Thalweg Profile - Reach 3**

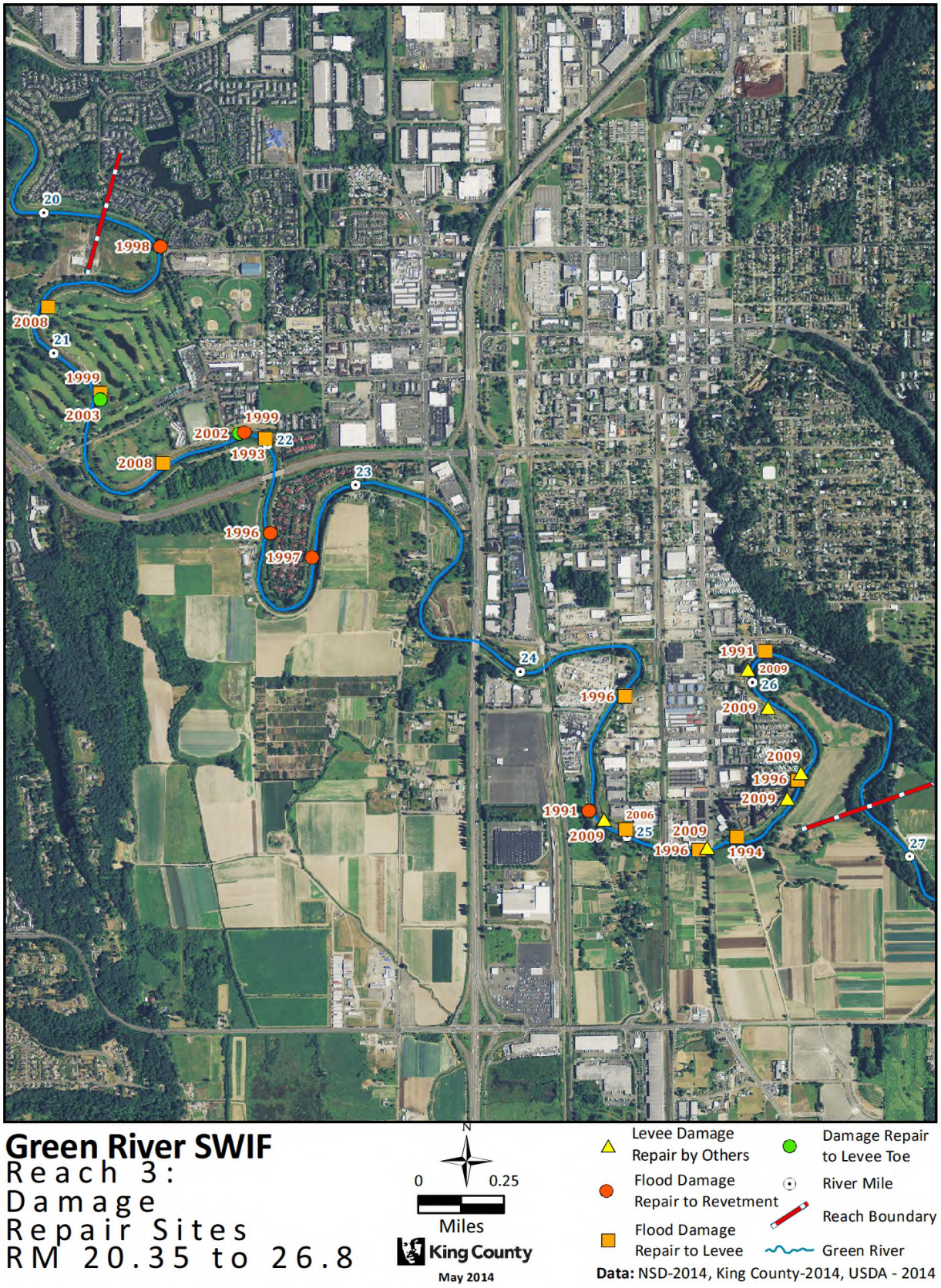


**Figure 12 - Reach 3 Damage Repair Sites**

### 4.1.4. REACH 4 -- RM 26.8 TO RM 32.

Geomorphologic Reach 4 encompasses PL 84-99 Levee System 5 and includes three levee segments, all of which are located along the left river bank. The three levees provide almost continuous left bank confinement; the Brannon Park – Reddington Levee extends from RM 28.6 – RM 29.5, the Galli's Levee from RM 29.5 – RM 29.71 and the Dykstra Levee from RM 29.71 to RM 30.79. The channel corridor is situated along the east side of the valley adjacent to the east valley wall. The river is characterized by a sinuosity of 1.4 and a valley gradient of about 0.0004.

Development in this area is largely agricultural in the northern (downstream) portion of the reach, and residential in the southern (upstream) part of the reach. The Auburn Golf Course and several small parks are also located adjacent to the river channel. Two roads cross the river, S. 277$^{th}$ Street and SE 320$^{th}$ Street. The east side of the river is directly bounded by Green River Road, 104$^{th}$ Avenue SE. John Reddington Road bounds a portion of the west side of the river from RM 28.6 to RM 29.18. Based on a review of aerial photographs, all roads appear to be leveed and/or well revetted.

Aside from the PL 84-99 Levee System noted above, levees and revetments, are present only sporadically throughout this reach. The longest continuous levee section extends along the left bank from RM 28.6 to RM 30.79. River sections downstream of this levee system contain only short discontinuous levees, and the upstream river section (RM 30.79 to RM 32.0) is largely unconfined. Within the confined section of the reach, the bank full width varies from 140 to 170 feet; through the unconfined sections the bank full with is generally much greater, ranging from 200 feet to over 400 feet where vegetated mid-channel bars have formed.

Only 1986 and 2006 FEMA Study cross sections are available for this reach. Review of the cross section data indicates that most of the reach has been subject to thalweg incision. The deepest incision is recorded at RM 27.56, where scour approaching 10.5 feet is recorded (Figure 13); the longitudinal thalweg profile is provided in Figure 14 for context and reference purposes. This site, shown on Figure 3, is located roughly 1,900 feet downstream from S 277$^{th}$ Street at the apex of a sharp, angular bend bounded by the Green River Road revetment, which may account for such deep incision. Only two other sites record incision greater than 3 feet, RM 28.99 and RM 30.59, both of which are located near the apexes of bends that are confined by revetted road embankments.

The map of levee/revetment damage repair sites (Figure 15) shows that all sites but one are located at or near the apexes of bends, the exception being a site at RM 29.5, which is located between two bends. This site is located just upstream of an area recording 2 feet of thalweg incision, although there is no clear indication the damage and incision are related.

The unconfined sections of Reach 4 are subject to channel migration (Perkins, 1993; NHC 2013). Perkins measured averaged migration rates of 3.8 feet per year over a 32 year period (1960 to 1992). NHC (2013) conducted a similar evaluation and measured a considerably larger average rate of 11 feet per year. NHC attributes the discrepancy to interpretation of "actively eroding". However, the difference may also be due to the availability of improved tools and differences in methodology. Regardless, migration rates of nearly 4 to 11 feet per year may pose a risk to existing levees and revetments that protect infrastructure, and to infrastructure not currently protected by levees or revetments.

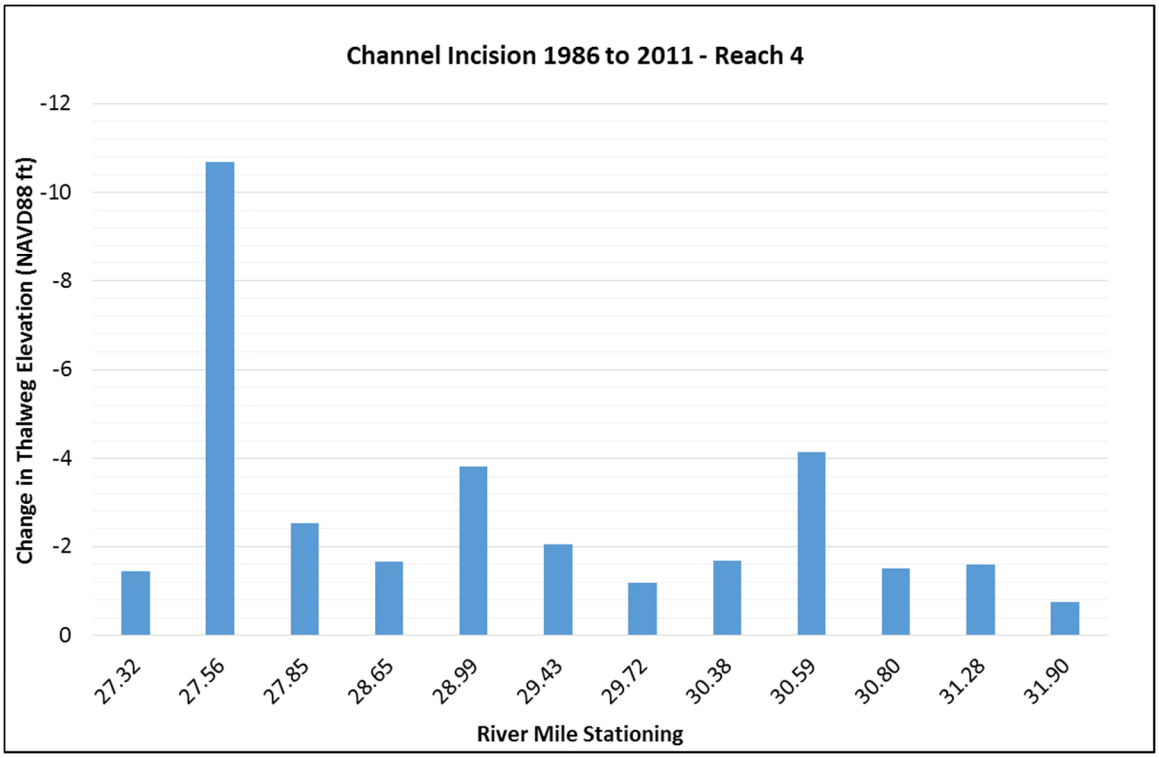


**Figure 13 - Incision Depth Bar Chart Reach 4**

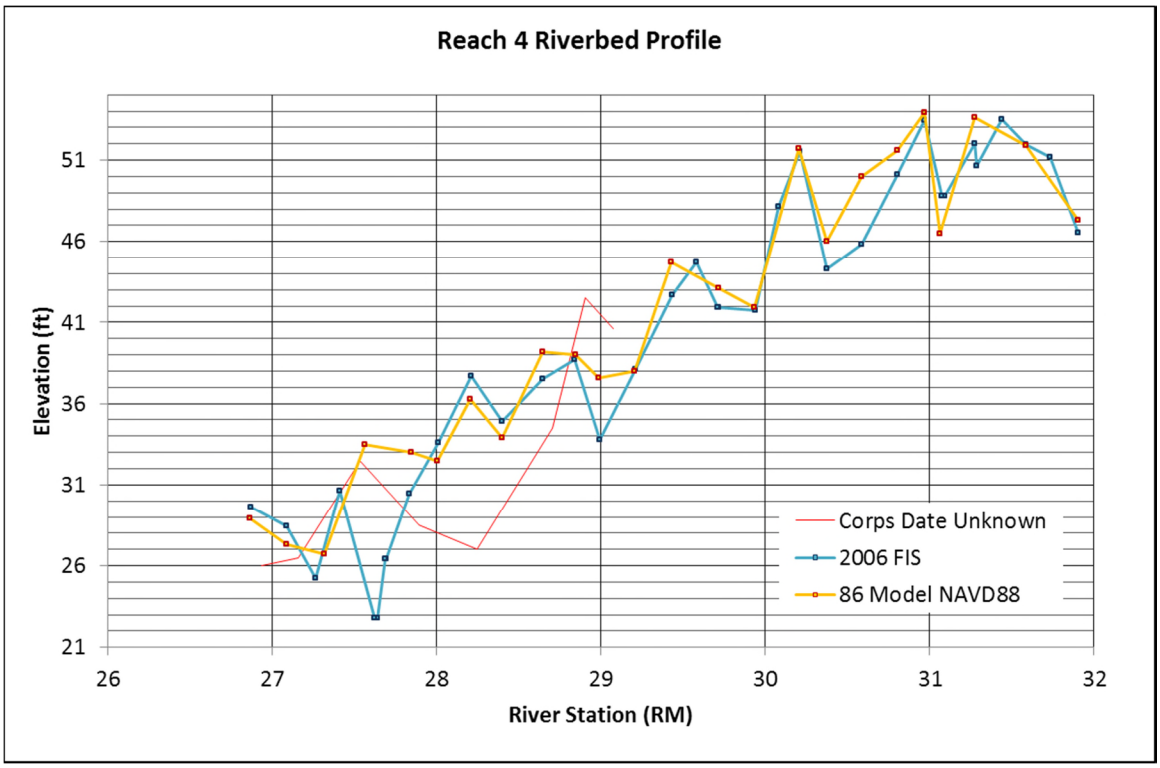


**Figure 14 - Longitudinal Thalweg Profile - Reach 4**

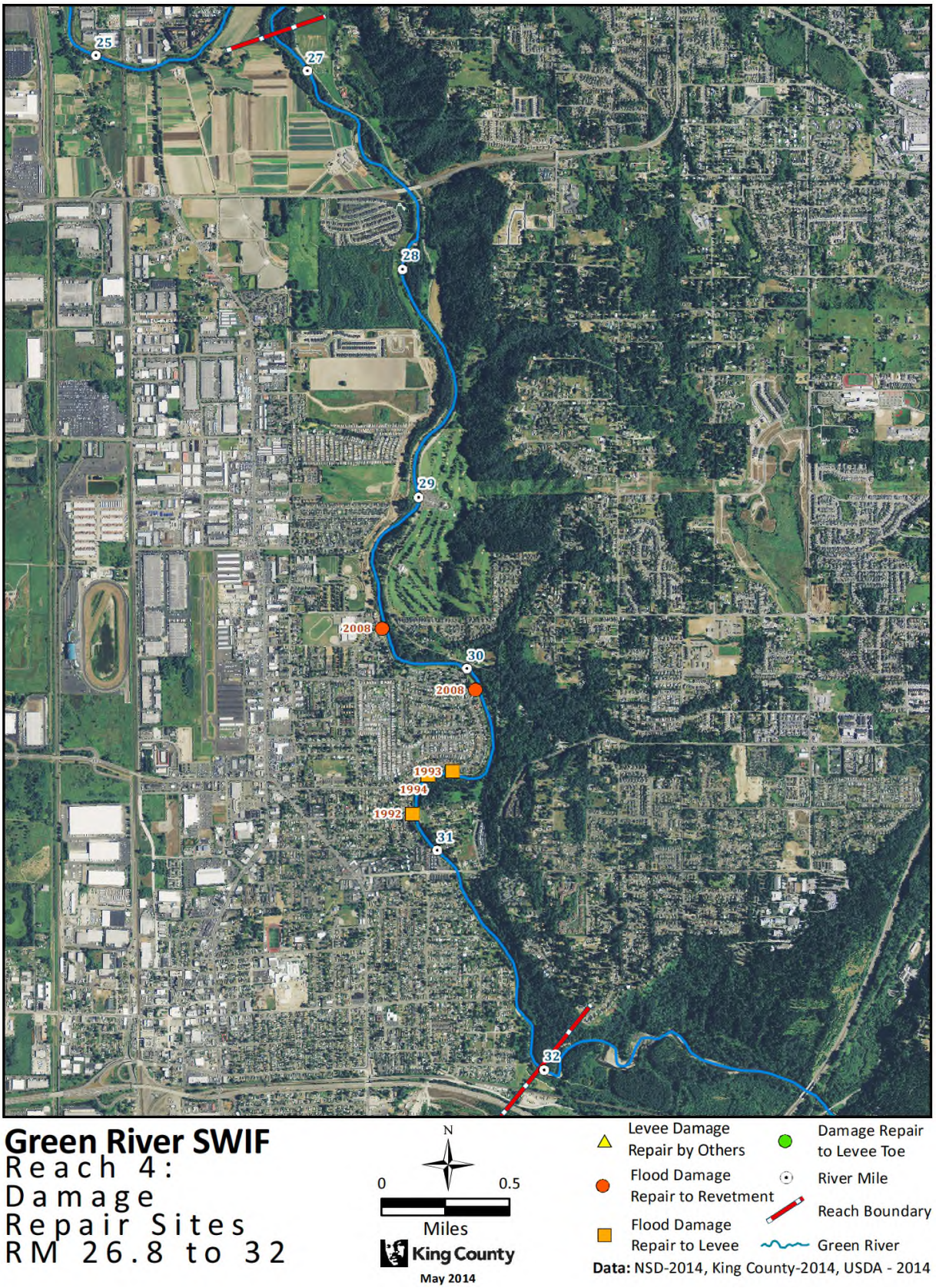


**Figure 15 - Reach 4 Damage Repair Sites**

# 5. FINDINGS

The lower Green River focus area between RM 32 and 11 is an anthropo-morphically altered river channel. The major alteration is clearing of riparian tree cover and tight confinement of the river channel by actively managed levees and revetments throughout Reach 1, 2 and 3, and portions of Reach 4. No changes in channel location or migration were observed in these reaches 1, 2, 3 and the confined portions of Reach 4, since 1986. The lack of migration is due to the presence of levees and revetments, which prevent bank erosion and confine the width of the active channel, which prevents development of point bars. This overall condition of Reaches 1, 2, 3, and the confined portions of Reach 4 have generated a simplified trapezoidal channel shape with sloping to near vertical side walls and channel bottoms prone to stream bed erosion and potential substantial incision.

Over the last several decades, stream bed erosion caused widespread lowering of the channel floor from 1 to 2 feet throughout the focus area. Based on close evaluation of changes in channel thalweg elevations, the average is exceeded at many bends in every reach, typically at the apex or on the downstream limbs of channel bends. Several of the bends record incision greater than 5 feet deep; the sites recording the deepest incision are at RM 15.85 (Reach 1), RM 17.00, 17.62 and RM 19.07 (Reach 2), RM 21.14 and RM 22.50 (Reach 3) and at RM 27.56 (Reach 4). As presented in the Reach descriptions, deep incision at or just downstream of a bend apex is typical since the bend apex is the portion of a sinuous channel margin subject to the highest high stage flow velocities and boundary shear stresses. Channel floor incision is typically exacerbated by the presence of levees and revetments, which harden the banks, thereby preventing lateral slope erosion, and thus increasing vertical bed shear stress along the toe of the levee.

Review of the damage repair sites indicates that most damaged levees and revetments are located around channel bends. An evaluation of stream bed incision sites and incision point suggests there is a strong link between incision, damage sites and channel bends. However, the link between substantial incision and recorded damage repair sites is not quite as strong; for example, some incision sites fall in the immediate vicinity of recorded damage repair sites while others, such as the deep incision at RM 15.85 (nearly 7 feet deep) do not. This inconsistency is more than likely a circumstance where the levee damage has not yet occurred, or been observed. In spite of this inconsistency, stream bed incision appears to be a good indicator of the likely damage locations.

These findings indicate that channel cross section sites recording greater than 5 feet of incision represent a substantial risk of future damage to adjacent levees and revetments. These findings also suggest that all tight channel bends be monitored for erosional damage to levee and revetment faces and toe structures.

While the cross –section evaluation and review of the damage sites was informative, geotechnical considerations combined with site visits by County staff offer more pivotal considerations in identifying potential breach locations for hydraulic modeling. Correlation between damage sites and incision points should be evaluated further as the SWIF planning process moves forward. Chapter 3 provides a reach level assessment to help inform planning considerations associated with alternative development.

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King County

# GREEN RIVER, KING COUNTY, WASHINGTON
# SYSTEM-WIDE IMPROVEMENT FRAMEWORK (SWIF)

Photo Credit: King County

## ATTACHMENT C:
# GEOTECHNICAL TECHNICAL MEMORANDUM

## FINAL

## MAY 2014

King County

# GREEN RIVER SWIF

# CURRENT CONDITIONS REPORT

# GEOTECHNICAL TECHNICAL MEMORANDUM

## FINAL

GeoEngineers

## MAY 2014

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# 1. Purpose and Scope

This memorandum summarizes the geotechnical assessment of the five Lower Green River PL84-99 levee systems between RM 12.44 and RM 30.79 as part of the Green River SWIF project. The location of the five levee systems are shown in Figure 1.1 and the levee names associated with each system are also shown in Table 1-1.

**Table 1-1. Green River PL84-99 Levee Systems**

| Levee System | River Bank | Levee Name | River Mile |
|---|---|---|---|
| 1 | Left | Tukwila 205 | 12.44 – 16.70 |
| 2 | Right | Desimone - Briscoe School<br>Boeing<br>Lower Russell - Holiday Kennel<br>Upper Russell - Soames Dolan<br>Kent Shops – Narita<br>Meyers Golf | 14.50 – 16.99<br>16.99 – 17.83<br>18.28 – 19.28<br>19.28 – 20.35<br>20.35 – 21.26<br>21.30 – 22.04 |
| 3 | Right | Signature Point | 22.77 – 23.18 |
| 4 | Right | Horseshoe Bend | 24.25 – 26.09 |
| 5 | Left | Reddington<br>Galli's<br>Dykstra | 28.60 – 29.18<br>29.50 – 29.71<br>29.71 – 30.79 |

The purpose of the geotechnical assessment is to:

- Summarize the existing stability condition of the levees based on review and findings from existing reports, studies and analyses.
- Identify the most significant geotechnical instability locations along the five levee systems based on review of previous reports and analyses. This effort was conducted to help the project team identify potential breach locations in the existing condition hydraulic and economic analysis.
- Characterize levee vulnerability to failure by reviewing and summarizing existing levee fragility curves and developing additional fragility curves to support the existing condition levee system analysis at six potential breach locations.

The existing levee stability conditions evaluation was completed by reviewing the following existing data reports that were provided:

- Levee setback feasibility reports for the 180$^{th}$ to 200$^{th}$ Street project (Tetra Tech, November 2012) and for the Reddington Levee Setback (Tetra Tech, November 2011)
- Technical memoranda from the Green River Levee Assessment project (Shannon & Wilson, 2007-2009)
- The King County Deficiency Action Plan spreadsheet and report (2013)
- Periodic inspection reports and continuing eligibility inspection reports
- Levee certification reports

Levee flood risk reduction facilities and improvements that were constructed prior to 2014 or will be constructed following completion of the above data reports, were also considered during the existing

condition evaluation when selecting potential levee breach locations. The current configuration, location and condition of flood risk reduction facilities, including the recently constructed and soon-to-be constructed secondary flood containment structures, as identified by King County, are presented in Table 1-2 below:

**Table 1-2. New and Proposed Flood Risk Reduction Facilities**

| Levee Reach | River Mile | Description | Status |
|---|---|---|---|
| Reddington | 28.6 – 29.5 | Levee setback | Construction complete |
| Reddington Extension | 28.2 – 28.6 | Levee setback | 90% design |
| Horseshoe Bend | 26.0 – 26.2<br>24.25 – 24.5 | Secondary levee and floodwall | Construction complete |
| Foster Park | 23.8 – 24.05 | Secondary levee | Construction complete |
| Hawley Road | 23.2 – 23.3 | Raised levee | Construction substantially complete |
| Upper Russell Road | 20.1 – 20.4<br>19.5 – 19.8 | Secondary levee<br>Secondary levee | 100% design, partially funded<br>Construction complete |
| Boeing | 17.0 – 17.2 | Secondary levee and floodwall | Construction Complete |
| Briscoe/Desimone | 16.9 – 17.0<br>16.0 – 16.4<br>15.45 – 15.6<br>14.5 – 14.6 | Raised levee and floodwall<br>Floodwall and bench<br>Floodwall and bench<br>Floodwall and bench | 30% design, funded<br>100% design, funded<br>100% design, funded<br>30% design, funded |
| Segale/Tukwila | 16.7 – 17.3 | Floodplain fill behind levee | Under construction |

Following the report and data review, the existing levee conditions were summarized with respect to geotechnical considerations as a basis for recommending potential breach locations for the levee failure scenario analysis. This data was used along with hydraulic considerations by the project team to select potential levee breach locations.

Levee vulnerability to potential breach failure was then characterized by reviewing and summarizing existing levee fragility curves and developing new curves at the six potential breach locations.

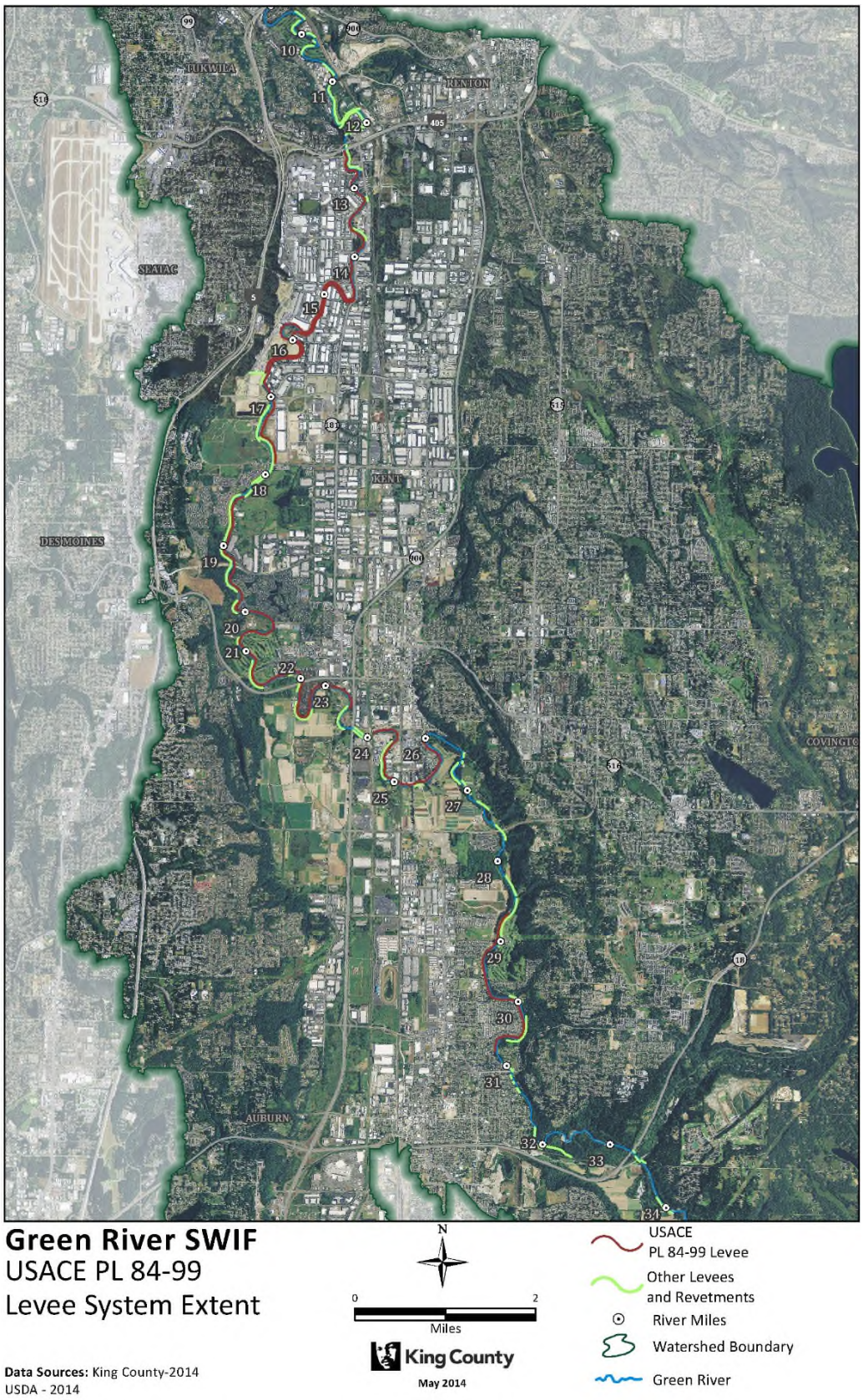


**Figure 1-1. Levee System Extent**

# 2. Data Review

## 2.1. Existing Reports

Existing levee conditions were evaluated by reviewing existing geotechnical studies including setback levee reports, technical memorandums regarding the Green River Levee Flood Damage Assessment completed in 2007 through 2009, the 2010 periodic inspection reports completed for the PL84-99 levees, the 2013 King County Deficiency Action Plan spreadsheet and report, and reports submitted for FEMA certification within the City of Kent. A complete listing of the reports provided is shown below in Table 2-1.

**Table 2-1 Green River Levee Geotechnical Reports**

| Title | Author | Date |
|---|---|---|
| 180th to 200th Street Levee Setback Study | Shannon & Wilson, Inc./ Tetra Tech | November 2012 |
| Reddington Levee Setback and Extension Feasibility Report, King County, Washington | Shannon & Wilson Inc./ Tetra Tech | November 2011 |
| Technical Memorandum TM 1000.105-1, Damage Reaches, Green River Levee Flood Damage Assessment, King County, Washington | Shannon & Wilson, Inc. | July 23, 2009 |
| Technical Memorandum TM 1000.305, Stage Probability of Failure Functions, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | July 23, 2009 |
| Technical Memorandum TM 1000.405-1, Flood Damage Analysis, Green River Levee Flood Damage Assessment, King County, Washington | Shannon & Wilson, Inc. | July 23, 2009 |
| Technical Memorandum TM 900.10-1, Field Reconnaissance, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | March 9, 2007 |
| Technical Memorandum TM 900.13-1, Summary of Existing Information, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | February 8, 2007 |
| Technical Memorandum TM 900.13-2, Review and Analysis of Existing Information, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | April 2, 2007 |
| Technical Memorandum TM 900.20-1, Geotechnical Exploration Methods and Results, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | March 29, 2007 |
| Technical Memorandum TM 900.20-2, As-Built Records of Piezometer Installations, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | February 2, 2007 |
| Technical Memorandum TM 900.20-3, Laboratory Test Methods and Results, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | March 27, 2007 |
| Technical Memorandum TM 900.30-1, Preliminary River Segmentation for Risk Analysis, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | May 15, 2007 |

**Table 2-1 (continued)**

| Title | Author | Date |
|---|---|---|
| Technical Memorandum TM 900.40-1, Results of Piezometer Studies, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | April 12, 2007 |
| Technical Memorandum TM 900.50-1, Deterministic Slope Stability Analyses, Green River Levee Assessment, King County, Washington | Shannon & Wilson, Inc. | June 20, 2007 |
| Periodic Inspection Reports for PL84-99 Levees (Lower Green, Briscoe, Boeing, Upper Russell, Lower Russell, Kent Shops, Meyers Golf, Galli's, Dykstra, and Reddington) | GeoEngineers/HDR | 2010 |
| King County Green River Levee Deficiency Correction Action Plan | King County | December 2013 |
| FEMA Accreditation Report, Green River Right Bank Levee, SR 516 to S 231st Way, Kent, Washington | GEI Consultants, Inc. | October 2011 |
| Stability and Certification Report, Briscoe/Desimone Levees, Kent, Washington | GeoEngineers, Inc. | October 24, 2011 |
| Geotechnical Evaluation Report, Boeing Levee Certification Project, Kent, Washington | Kleinfelder | October 14, 2011 |
| Levee Stability Analysis and Certification, Hawley Road Levee, Kent, Washington | GeoEngineers, Inc. | December 15, 2010 |
| Russell Road Lower-Lowest Levee, Levee Certification Report, Kent, Washington | AMEC | August 26, 2011 |
| Revised Levee Stability Analysis and Certification, Horseshoe Bend Levee, Kent, Washington | GeoEngineers, Inc. | October 28, 2010 |

## 2.2. Existing Levee Conditions

### 2.2.1. Original Construction

The Green River levees were constructed in the 1960s and 1970s using dragline methods that resulted in slope inclinations that typically vary from 1.4H:1V (horizontal to vertical) to 1.9H:1V. The levee fill was constructed with a combination of native alluvial soils and imported soil (typically silty sand with variable gravel content). Finished slopes were protected with a 2- to 3-foot thickness of 8-inch to 2-foot spalls and riprap.

Native soils encountered throughout the Green River Valley consist of interbedded layers of sand, silty sand and sandy silt (overbank deposits and upper alluvium). Occasional layers of organic silt and peat are also encountered in the upper alluvium. At depth, (typically about 30 to 40 feet below the existing ground surface) the alluvium becomes medium dense with less silt (sand and sand with silt). As noted above, the existing levee fill consists of a mixture of the alluvium and imported sand and gravel. The consistency of the levee fill typically varies from loose to medium dense.

Additional fill placement and levee raising has occurred in many areas, and secondary levees and floodwalls have also been constructed in recent years. Descriptions of the levee geometry, subsurface soils, and additional flood containment structures at each of the PL84-99 levees are discussed in the following section, PL84-99 Levee Configurations.

## 2.3. PL84-99 Levee Configurations

### 2.3.1. Tukwila 205

The Tukwila 205 levee is located along the left bank near the downstream end of the project, specifically between river mile (RM) 12.44 and RM 16.7. Levee heights measured from the landward toe are generally 5 feet or less in the downstream mile of the levee, and about 5 to 10 feet in height in the upstream portion. Crest widths are typically 10 to 20 feet in width with some being greater than 20 feet. One exception is in the vicinity of RM 14.5 to 15 where a crest width of less than 10 feet is reported. Steep riverside slopes are also noted in both the upstream and downstream portions of the levee (steeper than 1.5H:1V).

Floodplain fill and grading on the landward side of the levee has occurred in many areas of the Tukwila 205 reach within the last few years. Subsurface soil conditions within this reach typically consist of recent silty sand fill overlying interbedded very soft to medium stiff silt and very loose to medium dense sand with variable silt (overbank and alluvial deposits). Medium dense to dense older alluvial sands are typically encountered below the overbank and upper alluvial deposits at depths of about 30 to 40 feet below existing grade.

Groundwater levels fluctuate from a few feet below existing ground surface to as deep as 20 feet below ground surface in accordance with river stage and local rainfall.

### 2.3.2. Desimone Briscoe School

The Desimone Briscoe School levee extends between RM 14.5 and RM 16.99 on the right bank. Levee heights are typically 5 to 10 feet, and the crest width is typically 10 to 20 feet. Riverside slopes are steeply to moderately inclined, typically between 1.4H:1V to 2.25H:1V.

Existing subsurface soils within this reach include interbedded alluvial sands and silts. Alluvial soils in the area can be divided generally into a lower, older alluvial layer, and an upper, younger alluvial layer. The lower, older alluvium layer consists generally of dense clean sand with occasional layers of silty sand and isolated layers of silt. The upper alluvium layer consists of loose to medium dense sand with variable silt, and occasional layers of organic silt. Groundwater levels were encountered at a depth of about 4 to 8 feet below the existing ground surface during drilling within this reach. Groundwater is reported to flow from the river to the surrounding groundwater table during high river flows and toward the river during low river flows.

Modifications to the levees within this reach include sheet pile I-Walls being constructed in 2014 on the outside of the three major bends and at the tie-in at the South 200$^{th}$ Street Bridge. As presented in Chapter 3, slope instability and toe erosion are noted within the Desimone Briscoe School levee in the previous levee assessment studies and inspections, and in the 2013 Levee Deficiency Correction Action Plan.

### 2.3.3. Boeing

South of the Desimone Briscoe School levee, the Boeing levee continues along the right bank between RM 16.99 and RM 17.83. The Boeing levee is typically 5 to 10 feet in height, and 10 to 20 feet wide at the crest, but is setback about 125 feet from the Green River. Riverside slopes are moderately inclined at about 2H:1V.

The levee embankment soils are similar in composition to the underlying alluvium, consisting of loose to medium dense silty sand with gravel and sandy silt with gravel. The alluvial soils typically consist of medium dense sand with variable silt content with occasional layers of soft to medium stiff silt and organic silt. Groundwater levels were measured within the Boeing reach at about 18 to 19 feet below the ground surface in February 2011.

Recent levee improvements within the Boeing levee include construction of a secondary levee and floodwall at its downstream end.

### 2.3.4. Lower Russell – Holiday Kennel

Upstream of the Boeing levee, the Lower Russell - Holiday Kennel levee extends along the right bank from RM 18.28 to RM 19.28. Levee heights are less than 5 feet, and the crest width is greater than 20 feet. Riverside slopes are moderately steep between 1.5H:1V and 2H:1V, with some areas flatter than 2H:1V.

Reconnaissance reports of the existing levee and riverbank indicate there are areas of over-steepened slopes and surficial sloughing. Portions of the riverside slope are overgrown with blackberry vegetation and a few large trees were noted in some locations. Native vegetation is locally present at previous bioengineered revetment repair locations. Subsurface soils are reported to consist of a variable thickness of loose to medium dense silty sand and medium stiff sandy silt (fill) overlying overbank deposits and alluvium. The overbank deposits and alluvium are consistent with descriptions in other areas, consisting of interbedded silt, sand, and organic silt/peat, with cleaner fine to medium sand at depth. Groundwater levels were encountered at depths ranging from 10 to 33 feet below the existing ground surface during February and March of 2011.

A future setback levee is proposed along the right bank to attain the required freeboard and flood protection in this area.

### 2.3.5. Upper Russell – Soames Dolan, Kent Shops, and Meyers Golf

These levees extend from RM 19.28 to RM 22.04 along the right bank. Levee heights are typically in the range of 4 to 7 feet, with two locally higher reaches. The highest section has a height of about 15 feet and is located directly south of the South 231st Way bridge abutment. A second area is about 10 feet high and is located adjacent to a detention basin near RM 21.9. The levee crest width is typically greater than 20 feet at the downstream and upstream portions of the reach, and between 10 to 20 feet in the central area. Riverside slopes are typically inclined between 1.5H:1V and 3H:1V.

Subsurface soil conditions typically consist of interlayered soft silt and loose silty sand in the upper 30 to 35 feet, and medium dense to dense sand with variable silt content below this depth. Limited groundwater data within this reach indicates the groundwater level to be roughly 14 to 20 feet below the existing ground surface.

Secondary levees are under construction or soon-to-be constructed in this area to provide levee certification and accreditation.

### 2.3.6. Signature Point

Upstream of the Meyers Golf levee the Signature Point levee extends between RM 22.77 and RM 23.18 (this includes the County Road No. 8 levee). This levee is also less than 5 feet in height, and the crest width is greater than 20 feet. Riverside slopes are flatter than 2H:1V. Subsurface soil and groundwater conditions within the Hawley Road portion of the facility consist of roadway fill overlying interbedded

alluvial silty sand, sandy silt and medium dense sand. The roadway fill consists of an approximate 2- to 4-foot thickness of dense sand with variable silt and gravel. Underlying the fill, the silty sand and sandy silt alluvial layers alternate within the upper 25 to 40 feet and are typically loose to medium dense or medium stiff. Medium dense sand is present at depth. Groundwater was observed at a depth of about 25 feet during the explorations, corresponding to the approximately river level.

### 2.3.7. Horseshoe Bend

The Horseshoe Bend levee extends along the right bank between RM 24.25 and RM 26.09. The levee height within this reach is typically 5 to 10 feet and the crest width varies from about 10 to 25 feet. Riverside slopes are moderately steep to extremely steep, with some areas steeper than 1.5H:1V.

In general, the alluvial sands and silts within this reach are described to consist of an upper 20- to 30-foot layer of primarily loose to medium dense silty sand, overlying an approximately 15-foot thickness of medium dense to dense sand. Layers of sandy silt and silt separate the upper silty sand and the lower medium dense to dense sand in some areas. Groundwater was measured in September and December of 2009 within this reach at depths of about 15 to 23½ feet below the existing ground surface.

Secondary levees and floodwalls were constructed at both the extreme upstream and downstream portions of the Horseshoe Bend levee.

### 2.3.8. Reddington

The Reddington levee extends between RM 28.6 and RM 29.5 along the left bank. The levee was reconstructed and set back from the Green River in 2013. Levee heights in this area are typically less than 5 feet, with some areas between 5 and 10 feet in height. The levee crest width has recently been reconstructed to a width of 20 feet, and the reconstructed riverside slopes typically vary from 2.5H:1V to 3H:1V.

Subsurface soils within this area are described to consist of sandy gravel and silty sand (levee fill) overlying channel deposits of silt, sand and fine gravel. The channel deposits are described as very loose to dense and range from 2 to more than 25 feet in thickness. Overbank deposits consisting of very loose to medium dense silty fine sand to fine sandy silt, are encountered within the adjacent alluvial plain, ranging from 2 to 30 feet in thickness. Lake deposits of very soft to stiff clay/silt and peat deposits have been encountered west of the river within adjacent oxbow lakes in the downstream portion of this reach. Groundwater levels were measured at depths ranging from about 7 to 15 feet below the ground surface during June 2010.

### 2.3.9. Galli's

The Galli's levee is located upstream of the Reddington levee along the left bank between RM 29.5 and RM 29.71. Levee geometry is typically less than 5 feet in height with crest widths between about 10 and 20 feet. Riverside slopes are also steep to moderately inclined between 1.5H:1V to 2H:1V. Subsurface soil and groundwater information was not provided within this reach.

### 2.3.10. Dykstra

The farthest upstream levee in the study area is the Dykstra levee along the left bank between RM 29.71 and RM 30.79. This levee is also less than 5 feet in height with crest widths up to 20 feet. Recent borings were completed by King County to a depth of about 23 to 24 feet near RM 30.5 within this reach. In general, subsurface soils consist of medium dense grading to very loose sand and silty sand fill

to a depth of about 7½ feet below the ground surface. Explorations were completed in the backyard of the residence located at 1610 Riverview Drive NE. Interlayered medium dense to dense gravel and sand underlies the upper very loose fill. Groundwater was observed at a depth of about 10 feet during drilling.

## 2.4. Stability Analyses

Shannon & Wilson completed six triaxial compression tests during the 2007 Green River Levee Assessment Study (TM 900.50-1) and concluded that, regardless of material classification, the strength of the subsurface materials could be adequately characterized by a friction angle of about 36 degrees. However, conclusions in the same study state that, based on reconnaissance observations, the slopes in these soils are able to stand at greater angles. This conclusion was likely based on the presence of riprap, root structure, and cohesive soil layers that add strength to the subsurface profile. Accordingly, a homogeneous cross section with a cohesion of 30 pounds per square foot (psf) and a reduced friction angle of 35 degrees was selected for their studies.

Soil strength parameters used in stability analyses of the Green River Levees in other studies has varied from 28 degrees for the sandy silt and silt layers, and 31 to 34 degrees for the loose to medium dense sandy alluvium, to as high as 38 degrees for the dense sand layers encountered at depth (below a depth of about 30 to 40 feet). The results of stability analyses assuming a homogeneous layer (Shannon & Wilson) and a varied subsurface profile (other studies) are similar and indicate that shallow failure surfaces on the riverside slopes do not meet the minimum factors of safety (FOS) criteria as specified by USACE, Design and Construction of Levees, April 30, 2000 (EM 1110-2-1913). A description of the USACE analyses cases are described below.

Slope stability analyses were completed in the certification reports for four cases as recommended by USACE as described below. Stability analyses completed in the Shannon & Wilson 2007 study (TM 900.50-1) included all cases except End of Construction. The recommended USACE analyses cases include:

- **End of Construction.** This case is based on the current condition of the levee or the post-construction condition of improved levees. The water level in the river is assumed to be at mean annual flow for this analysis.
- **Steady State Seepage.** The levee stability is evaluated under flood conditions assuming a river level at the Base Flood Elevation and assuming that seepage through the levee has achieved a steady state. Stability of both the riverside and landside slopes are considered.
- **Rapid Drawdown.** The levee stability under rapid drawdown conditions was typically analyzed using a transient seepage analyses assuming a drawdown rate ranging from 1 foot per hour to 2 feet per day. Piezometer data suggests that at high river stages, the groundwater level in the levees was less than the river level and that wasn't until the river stage had dropped significantly that the groundwater level in the levees was higher than the river level. Therefore "rapid" drawdown may be limited to a relatively short-term differential head of a few feet within the lower portion of the riverside slope.
- **Seismic.** Seismic stability of the levee was considered under both liquefied conditions and using pseudostatic analysis. Liquefied conditions assumed a reduced soil strength profile. Pseudostatic conditions assumed varied horizontal accelerations including the peak ground acceleration for the 100-year return period earthquake, the 10 percent in 50-year earthquake (475 return period), and site specific site-response analyses. Where inadequate FOS were achieved, estimated slope displacements were calculated using the USGS method developed by

Jibson and Jibson in 2003. The results indicated that deformation under the design seismic acceleration is on the order of a few inches. Settlement and lateral spreading may also occur as the result of liquefaction of the sandy soils below the groundwater level. Liquefaction settlement was typically evaluated to be on the order of 6 to 8 inches, while finite difference dynamic numerical modeling indicated lateral spreading up to about 2 feet of displacement and 2 feet of settlement at the riverside crest.

In general, each analysis case resulted in shallow failure surfaces that do not meet the USACE recommended factors of safety. However, the failure surfaces that do not meet the criteria were reported to be shallow such that they would not result in significant reduction of the levee prism. Conclusions in the studies considered the shallow failures as maintenance issues that would not result in a levee breach.

## 2.5. Characteristics of Existing Fragility Curves

Conditional probability-of-failure versus floodwater elevation (fragility curves) were previously developed at ten locations along the Green River levees. Eight of the fragility curves were developed as part of the Lower Green River Risk Assessment (TM 1000.305, Shannon & Wilson, July 23, 2009), and the remaining two were developed as part of the 180$^{th}$ to 200$^{th}$ Street Levee Setback Study (Tetra Tech, November 2012). Because the analytical methods varied between the studies, only the fragility curves presented in the Lower Green River Risk Assessment were utilized to develop fragility curves for the current selected breach locations (refer to Chapter 5 for the methodology used to develop new fragility curves).

Multiple failure modes were evaluated to develop the composite probability of failure during development of the existing fragility curves presented in the Lower Green River Risk Assessment. Individual failure modes included:

- **Under Seepage**. The evaluation of the probability of levee failure due to under seepage was based on methods described by USACE (EM 1110-2-1913). Using the levee dimensions and material properties, the probability of the exit hydraulic gradient exceeding the critical gradient of the blanket material (located near the landside toe) was determined. The critical gradient was calculated as the buoyant unit weight of the blanket material divided by the unit weight of water.
- **Through Seepage**. Through-seepage analysis was computed as the probability of the exit hydraulic gradient on the landside slope of the levee exceeding the critical gradient of the levee material. The exit gradient was estimated assuming that the line of seepage would exit parallel to the levee face. Using this simplified model, the only random variable was the critical gradient of the levee material, which was computed as the buoyant unit weight of the levee material divided by the unit weight of water.
- **Slope Stability (Steady State, Rapid Drawdown, and Seismic).** Slope stability analyses were completed in general accordance with USACE (EM 1110-2-1913). Two seepage cases (steady state and rapid drawdown) and a seismic loading case were included as potential failure modes. Failure surfaces were analyzed for entry points located at the riverside, middle, and landside of the levee crest for both the riverside and landside faces of the levee. The probability of levee failure that could lead to flooding was considered in the analyses by assigning a progressively higher probability as the failure surface resulted in greater loss of the levee prism. Higher probabilities were also assigned to slip surfaces on the riverside slope on the basis that a riverside slope would expose erodible internal levee material potentially leading to scour,

additional instability, loss of freeboard, and a greater potential for breaching. The assigned probabilities of levee failure for a given slope failure surface that was included in the analyses are shown in Table 2-2.

**Table 2-2. Assigned Probability of Levee Failure for Given Slope Failure Surface**

| Bank of Slope Failure | Probability of Flooding Due to Failure Surface with Specified Entry Point | | |
|---|---|---|---|
| | Near Riverside Edge of Crest | Near Center of Crest | Near Landside Edge of Crest |
| Riverside | 0.05 | 0.30 | 0.95 |
| Landside | 0.90 | 0.15 | 0.01 |

- **Judgment.** Judgmental evaluation is often factored into the composite failure curve based on observations during the visual inspection (such as animal burrows, cracks, roots, and poor maintenance). Engineering judgment conditions considered during development of the existing Green River levee fragility curves included consideration of potential levee failure due to scour, animal burrowing or cracking, failure due to vandalism, the presence of seams of weak material, and poor maintenance. However, due to cost and complexity, a quantitative inventory or detailed analysis of these conditions and the effects to levee instability have not been analyzed or incorporated into the Green River levee fragility curves.

For each of the above failure modes, a stage-probability of failure function was developed using the Taylor's Series Mean Value Method (USACE, 1992, 1995, 2003). Following development of the probability of failure function for each failure mode, a composite probability of failure was determined. This was achieved by calculating the composite reliability (probability of no failure) as the product of the reliability values for each failure mode. The composite probability of failure was then determined by subtracting the composite reliability from one.

The composite fragility curves previously developed for the Green River levees were most influenced by the rapid drawdown, seismic, and underseepage failure modes. Based on review of levee conditions at the existing fragility curve sites, the levee height, riverside slope, and gradient landward of the landside levee toe strongly influence these failure modes.

The previously developed fragility curves indicate a composite probability of failure ranging from about 0.1 to 2 percent when the river stage is within one foot of the landside levee toe, to 0.2 to 6 percent when the river stage is one foot below the levee crest. The composite probability of failure is based on the existing condition geometry of the levee. Scour-impacted cross sections or changes in the existing levee cross section due to other factors were not considered during fragility curve development, which may result in greater probability of failure. Consideration of scour was incorporated in the judgment evaluation on a qualitative basis.

# 3. Levee Vulnerability and Reconnaissance Ratings

Geotechnical information summarized in the levee certification reports, periodic inspection reports, the 2013 Levee Deficiency Correction Action Plan, and the Green River Levee Flood Damage Assessment

memoranda including segmented levee reconnaissance data, were reviewed as a basis for providing geotechnical vulnerabilities for selecting preliminary breach locations.

As presented in Technical Memorandum TM 900.10-1 by Shannon & Wilson (TM 900.10-1), a field reconnaissance of the Green River levees was completed along both banks between RM 6.3 and 32 to assess levee characteristics and to rate physical features. Reconnaissance scores were developed for similar segments of each levee section (segment lengths are typically 0.1 to 0.5 mile). Physical attributes of the levees were rated in the following categories:

- Levee Geometry (height, top width, riverside slope, and landside slope)
- Revetments and Erosion (revetments, slope face, animal signs)
- Land Use and Infrastructure
- Maintenance and Inspection
- River Hydraulics (channel direction and channel depth)
- Geology and Soils

Individual attributes were assigned a score of 1, 2, or 3 for each segment of a facility, with a higher score generally indicating a greater likelihood of failure or damage. Three attributes did not follow this convention (top width, riverside slope, and landside slope) in the original reconnaissance data summarized in TM 900.10-1. The numerical scores of these attributes were reversed to follow the convention of increasing score for greater degree of likelihood of failure prior to use in evaluation of potential breach locations. The levee reconnaissance rating system is shown below in Table 3-1.

**Table 3-1. Levee Reconnaissance Rating System, Green River Levee Assessment, TM 900.10-1, March 2007**

| Attribute* | | Score | Description |
|---|---|---|---|
| Levee Geometry | Height | 1 | <5 feet |
| | | 2 | 5 to 10 feet |
| | | 3 | >10 feet |
| | Levee Top Width | 1 | >20 feet |
| | | 2 | 10 to 20 feet |
| | | 3 | <10 feet |
| | Riverside Slope | 1 | >2H:1V |
| | | 2 | 1.5 – 2H:1V |
| | | 3 | <1.5H:1V |
| | Landside Slope | 1 | >2H:1V |
| | | 2 | 1.5 – 2H:1V |
| | | 3 | <1.5H:1V |
| Revetments and Erosion | Revetments | 1 | Protected Toe, No Sign of Erosion |
| | | 2 | Marginal Toe, Some Signs of Erosion |
| | | 3 | No Slope Vegetation or Rock, Erosion/Sloughing Evident |
| | Slope Face | 1 | Slope Vegetated or Rock Protected, No Sign of Erosion |
| | | 2 | Slope Vegetation or Rock Sparse, Some Erosion |
| | | 3 | No Slope Vegetation or Rock, Erosion/Sloughing Evident |
| | Animal Signs | 1 | No Sign of Burrows |
| | | 2 | Few Signs of Burrows |
| | | 3 | Significant Sign of Burrows |
| Land Use and Infrastructure | Protected by Levee | 1 | Undeveloped or Agriculture |
| | | 2 | Sparse Residential/Commercial/Industrial |
| | | 3 | Heavy Residential/Commercial/Industrial |
| | Value | 1 | Land and/or Crops |
| | | 2 | Few Structures and/or Infrastructure |
| | | 3 | Many Structures and/or Infrastructure |
| Maintenance and Inspection | Repair History | 1 | No Known Repairs |
| | | 2 | Suspected or Known Minor Repairs |
| | | 3 | Suspected or Known Major Repairs |
| | Current Condition | 1 | Appears Well Maintained and in Good Condition |
| | | 2 | Appears Marginally Maintained and in Marginal Condition |
| | | 3 | Appears Poorly Maintained and in Poor Condition |
| | Access | 1 | Good Access and Visibility |
| | | 2 | Adequate Access and Poor Visibility |
| | | 3 | Poor Access and No Visibility |
| River Hydraulics | Channel Direction | 1 | No Impingements |
| | | 2 | Impingement but No Effect on Levee or Slope |
| | | 3 | Impingement Effecting Levee or Slope |
| | Channel Depth | 1 | Inside Bend |
| | | 2 | Straight |
| | | 3 | Outside Bend or Impingement (Thalweg along Toe) |

* Geology and Soils were also identified as an attribute but were not scored during the reconnaissance. This was based on no predictable differences being discernable during review of the subsurface data, and results of laboratory testing were similar despite the variability of material samples.

Levee reconnaissance ratings noted in Table 3-1 between River Miles 6.3 and 32 were utilized to evaluate vulnerability to failure for this study and to develop potential breach locations for preliminary evaluation. This was achieved by calculating a weighted reconnaissance score considering the attributes of levee geometry, revetments and erosion (excluding animal signs because of limited exposures), and channel direction and depth. Categories for land use and infrastructure, and maintenance and inspection were not included because they did not pertain to levee stability. The scoring system is included in the table for consideration of these attributes in the future. Geology and soils were also not utilized because consistent geology, subsurface conditions, and material properties were reported. Table 3-2 below summarizes geotechnical vulnerabilities throughout the study area used to develop 15 preliminary breach locations for consideration. The locations are also shown in Figure 3.1.

With the exception of two locations, weighted scores greater than 53 were selected as preliminary breach locations and prioritized by the weighted score calculation (column 5 of Table 3-2). Recent flood risk reduction facilities noted in Table 1-2 were considered when selecting preliminary breach locations. For example, if a recent floodwall or secondary levee was constructed within a RM segment of a high reconnaissance score, this segment was not selected as a preliminary breach location. The selection of the RM within the segment was based on the following criteria:

- If an existing fragility curve was located within the segment, the RM of the fragility curve was selected as the breach location.
- Where fragility curves were not available, the RM was selected where an instability or deficiency was noted (as listed in the 2007 Reconnaissance column and the 2010/2013 Inspection and Deficiencies column).
- If a fragility curve was not available and an instability was not noted within the segment, the RM was selected based on the location of an outside bend.

Two locations with a score of less than 53 were selected based on the available fragility curve (location 14), and seepage noted during flood conditions (location 15).

**Table 3-2. Preliminary Breach Locations**

| Location No. | River Mile | Bank | Levee Reach | Calculated Weighted Score | Outside Bend | Selection Comments | | | Other Notes or Improvements Since 2007 Reconnaissance |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Existing Fragility Curve | 2007 Reconnaissance | 2010/2013 Inspection and Deficiencies | |
| 1 | 14.83 | Left | Tukwila 205 | 62 | Yes | Yes | Inspection data within segment 14.47 to 15.04 | | Potential fill area |
| 2 | 16.56 | Left | Tukwila 205 | 60 | Slight | Yes | Inspection data within segment 15.90 to 16.83 | | Grading on landside to Elevation 34 feet per Tukwila South Project |
| 3 | 26.05 | Right | Horseshoe Bend | 59 | Yes | Yes, at 25.995 | Inspection data within segment 25.90 to 26.21; | | Improvements not in levee prism |
| 4 | 25.69 | Left | Other levee/ revetment | 59 | Yes | No | Inspection data within segment 24.56 to 25.90 | | |
| 5 | 16.85 | Right | Desimone-Briscoe School | 58 | No | Yes | Inspection data within segment 16.38 to 17.12 | | Nearby floodwall and bench |
| 6 | 30.65 | Left | Dykstra | Detailed data not available | Yes | No | High Score on May 2007 Weighted Reconnaissance Figure | | |
| 7 | 20.03 | Right | Upper Russell – Soames Dolan | 58 | No | No | Slough noted in Table 2 of March 2007 TM, inspection data within segment 20.00 to 20.20 | | |
| 8 | 16.59 | Right | Desimone-Briscoe School | 58 | No | No | Cracks, slump noted in Table 2 of March 2007 technical memorandum, and inspection data within segment 16.38 to 17.12 | Slope instabilities noted upstream and downstream/ sloughing in deposited sediments and toe erosion | |
| 9 | 11.05 | Left | Other levee/ revetment | 55 | Yes | No | Inspection data within segment 11.05 to 11.71 | | |
| 10 | 16.83 | Left | Other levee/ revetment | 55 | No | No | Cracks/instability noted in Table 2 of March 2007 technical memorandum, and inspection data within segment 16.83 to | Depression noted in 2010 and in 2013 deficiency report | |

| Location No. | River Mile | Bank | Levee Reach | Calculated Weighted Score | Outside Bend | Selection Comments | | | Other Notes or Improvements Since 2007 Reconnaissance |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Existing Fragility Curve | 2007 Reconnaissance | 2010/2013 Inspection and Deficiencies | |
| | | | | | | | 17.12 | | |
| 11 | 13.57 | Left | Tukwila 205 | 54 | Yes | Yes | Inspection data within segment 13.50 to 13.65 | | Potential fill area |
| 12 | 19.89 | Left | Other levee/ revetment | 54 | Yes | No | Inspection data within segment 19.6 to 20.00 | | |
| 13 | 15.10 | Right | Desimone-Briscoe School | 53 | No | Yes | Inspection data within segment 14.62 to 15.20 | Slope instabilities noted upstream and downstream/ sloughing in deposited sediments and toe erosion | Nearby floodwall and bench |
| 14 | 15.75 | Left | Tukwila 205 | 48 | Yes | Yes | Inspection data within segment 15.04 to 15.90 | | Grading on north per Tukwila South Project |
| 15 | 19.29 | Right | Upper Russell-Soames Dolan | 39 | No | No | Inspection data within segment 19.15 to 19.34 | Seepage noted during flood conditions in 2013 deficiency report | |

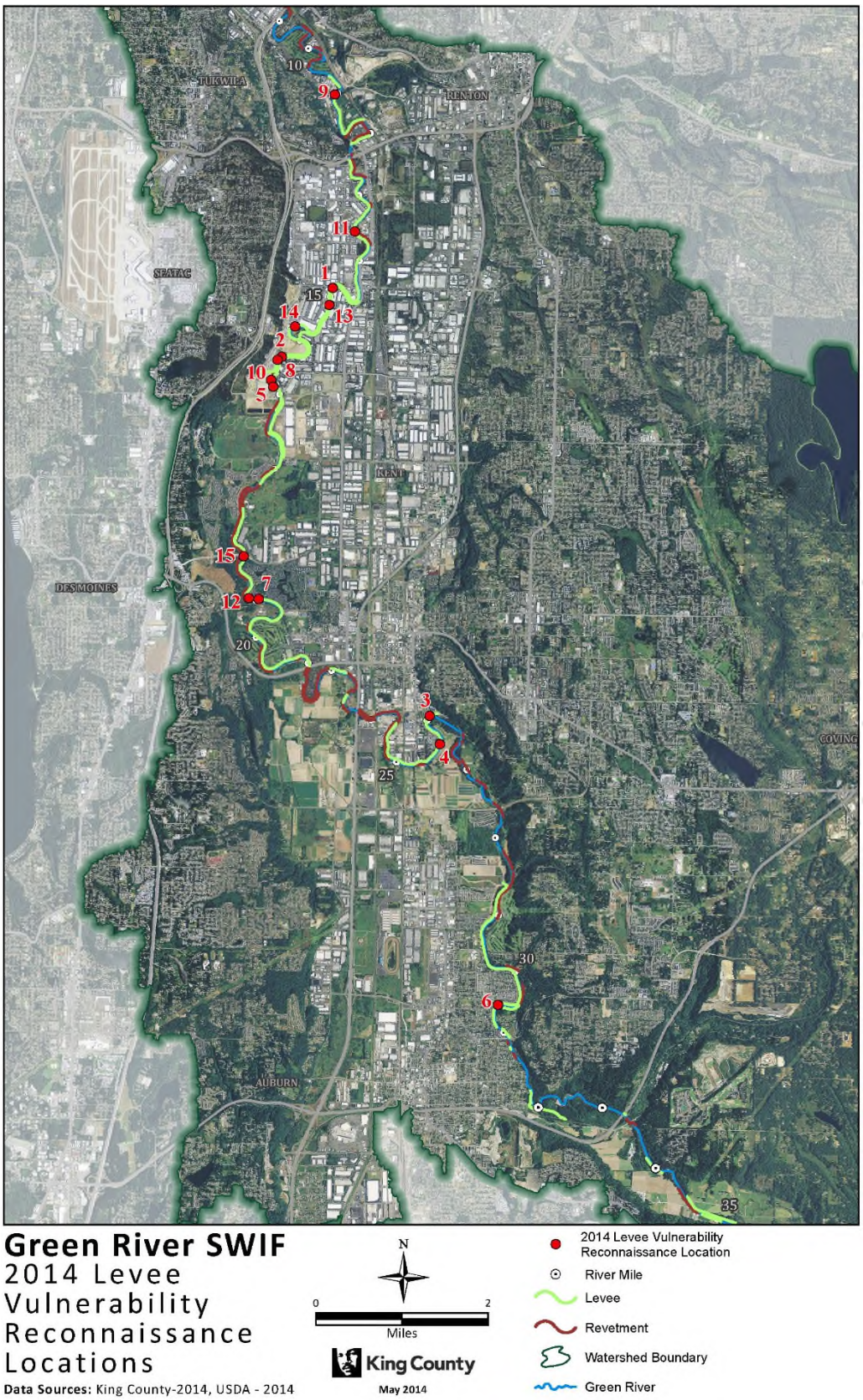


**Figure 3-1. 2014 Levee Vulnerability Reconnaissance Locations**

# 4. Potential Breach Locations for Fragility Curve Development

Using the preliminary breach location data and previous experience with the Green River levees, the project team of King County, Tetra Tech, and NHC selected six potential breach locations where fragility curves would be developed to support the levee system analysis and characterization of flood risk. The potential breach locations are shown in Table 4-1. Fragility curves were developed at each of these locations as described in Chapter 5 below.

**Table 4-1. Selected Potential Breach Locations (see Figure 5-1)**

| Potential Breach No. | Levee Reach | River Bank | River Mile |
|---|---|---|---|
| 1 | Dykstra | Left | 30.69 |
| 2 | Tukwila 205 | Left | 14.83 |
| 3 | Horseshoe Bend | Right | 25.50 |
| 4 | Meyers Golf | Right | 21.80 |
| 5 | Lower Russell Road | Right | 18.60 |
| 6 | Briscoe-Desimone | Right | 16.62 |

Four of the six selected potential breach locations have a weighted reconnaissance score of 53 or greater. The remaining two locations, Meyers Golf and Lower Russell Road were selected by the design team. The breach locations are shown in Figure 5.1.

# 5. Fragility Curve Development

Of the six potential breach locations, only one has a previously developed fragility curve, Tukwila 205. In order to develop the remaining five fragility curves, we adopted an empirical method based on comparing levee geometry to the existing fragility curves and considering the most influential failure modes.

Accordingly, fragility curves were developed at the remaining five locations by comparing the levee geometry including the levee height, slope inclinations, base width, crest width, and the slope gradient beyond the landside toe to the levee geometry of the existing fragility curves. Each of these geometric conditions strongly influence the failure modes. Topographic information at each breach location was provided by NHC. Levee geometry at each of the breach locations is shown in the attachment, Figures 1 through 6.

Geometric comparisons were made when considering the most influential failure mode (i.e., the slope gradient landward of the landside toe and levee height when considering underseepage influence, the riverside slope inclination when considering the seismic influence, and the riverside slope inclination and levee height when considering rapid drawdown).

The locations of the fragility curves for the potential breach locations are shown in Figure 5.1, and the curves are included in the attachment in Figures 7 through 12. The composite probability of failure (y-axis) at the river stage of 1 foot above the landside levee toe, and 1 foot below the levee crest for the most similar levee section was utilized to develop the new fragility curve. In addition to developing the composite probability of failure by comparing geometry and probability of failure modes (the lower green line in attached Figures 7 through 12), the maximum probability of failure previously generated for all breach locations is shown (the upper blue line in attached Figure 7 through Figure 12).

Stage-discharge curves developed and summarized in the hydraulics technical memorandum are included below for comparing river stages at various locations to the flow at the Auburn gage.

**Table 5-1. Stage Discharge Data from Hydraulics Technical Memorandum**

| | **Breach** | **Dykstra** | **Horseshoe Bend** | **Meyers Golf** | **Tukwila** | **Duwamish** |
|---|---|---|---|---|---|---|
| | **River Mile** | **30.80** | **25.55** | **21.83** | **14.93** | **10.68** |
| **Flood Event** | **Flow at Auburn (cfs)** | **Stage (ft)** | | | | |
| 91% AEP Median | 3,500 | 58.67 | 37.45 | 29.26 | 19.78 | 12.88 |
| 50% AEP High C.L. | 9,900 | 64.15 | 47.13 | 39.03 | 28.7 | 20.62 |
| 10% AEP Low C.L. | 12,000 | 65.51 | 50.04 | 41.56 | 30.57 | 21.75 |
| 0.5% AEP Median | 12,600 | 65.9 | 51.07 | 43.22 | 31.68 | 22.5 |
| 1% AEP High C.L. | 15,100 | 67.3 | 52.42 | 44.49 | 32.98 | 23.43 |
| 0.2% AEP Median | 18,800 | 69.01 | 53.6 | 45.85 | 33.95 | 24.98 |
| 0.2% AEP High C.L. | 26,800 | 71.07 | 54.56 | 46.67 | 34.43 | 26.27 |

To validate the empirical fragility method, we generated a new fragility curve for one of the existing curves using only the levee geometry and comparing the conditions to the existing probability of failure curve data. The results were consistent with the existing curve data that was generated by the Taylor's Series Mean Value Method.

We understand the flood damage reduction analysis software requires the probability of levee failure be 1.0 at the crest of the levee. We are in agreement with the previous method of holding the probability of failure constant for a river stage of one foot below the levee crest until 0.1 feet below the crest to avoid unrealistically high probabilities of failure near the crest. The river stage increase within one foot of the levee crest does not have an exponential increase in probability of failure.

Following fragility curve development, Breach Nos. 1 through 4 were selected by the design team for inclusion in the system-wide levee failure scenarios as part of the hydraulic and flood risk analysis tasks. The four selected breach locations are shown in Figure 5.2.

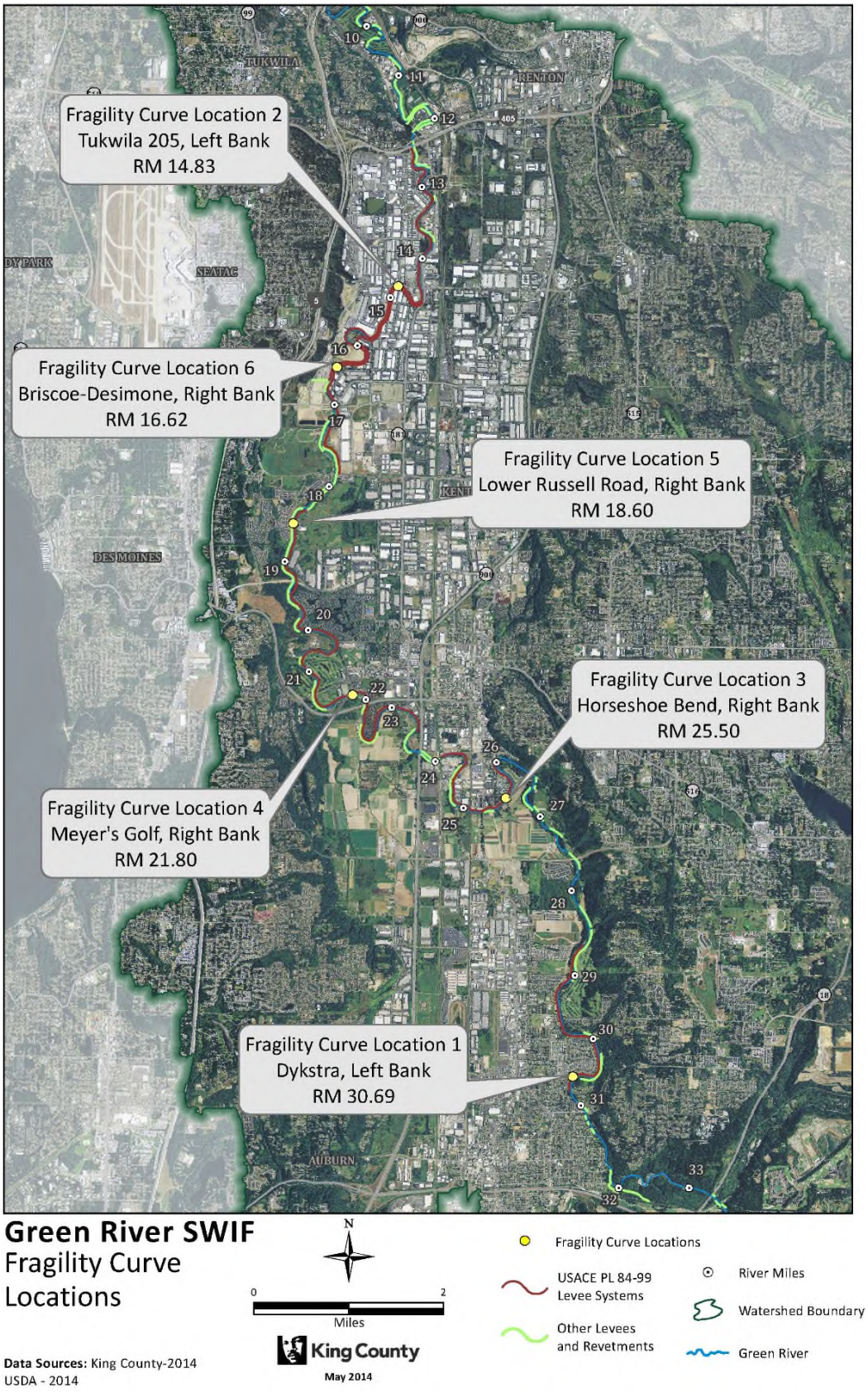


**Figure 5-1. Fragility Curve Locations**

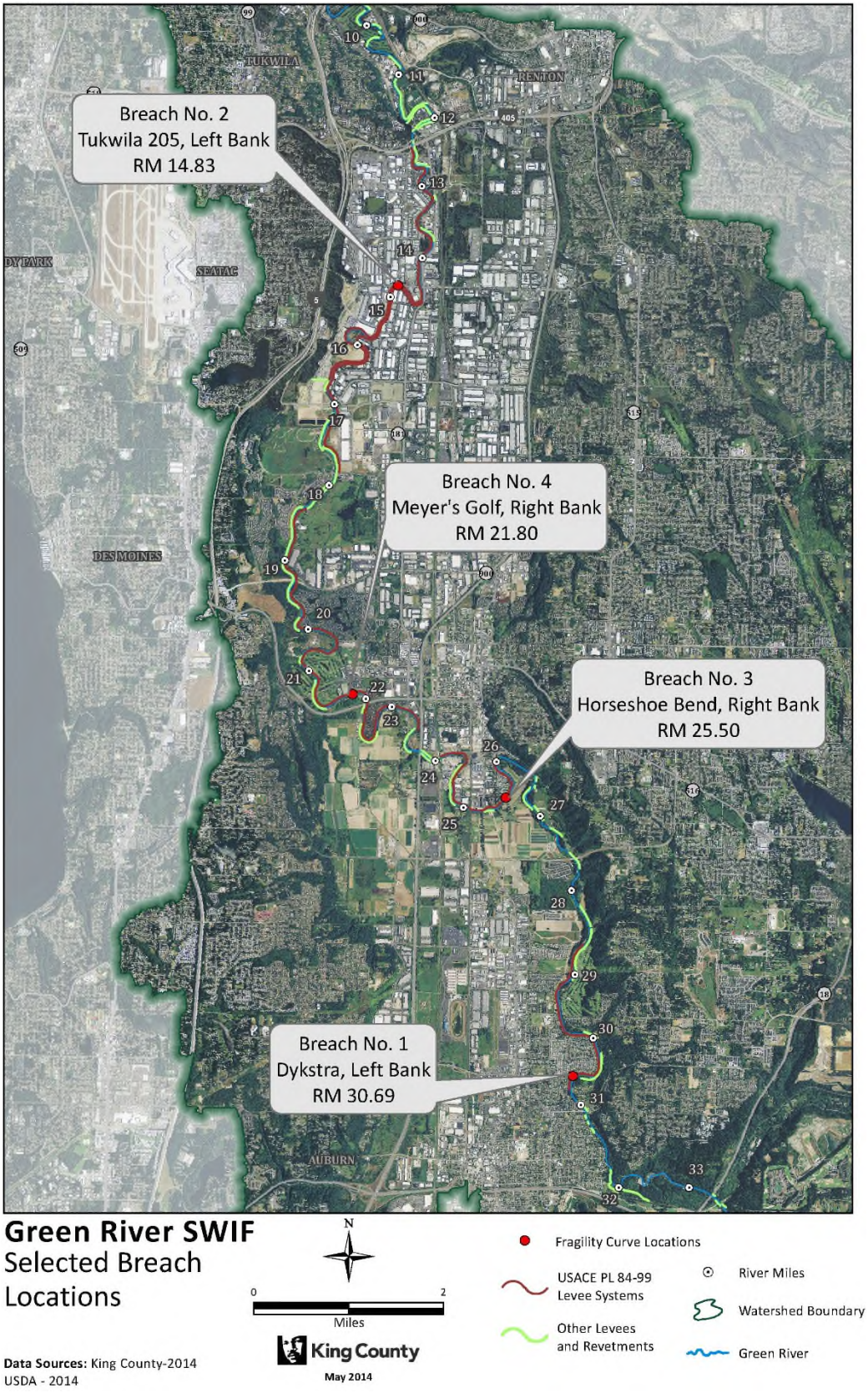


**Figure 5-2. Selected Breach Locations**

# 6. FINDINGS

Subsurface soil and groundwater conditions and results of stability analyses summarized in the available geotechnical reports are relatively consistent for the PL84-99 levee systems. Previous stability analyses for the levees indicate that shallow failure surfaces do not meet the USACE recommended factors of safety. However, the failure surfaces that do not meet the criteria were reported to be shallow such that they would not result in significant reduction of the levee prism. Conclusions in the studies considered the shallow failures as maintenance issues with a low probability of causing a levee breach. However, repairs of the shallow failures are considered more than routine maintenance issues because the levees were not constructed to modern standards to include adequate toe and slope protection with a compacted engineered fill.

The composite fragility curves developed for the Green River Levee Assessment and for this study appear to support the conclusion that there is low probability of a failure causing a levee breach. Relatively low probability of failure was calculated for each potential breach site. The composite probability of failure at lower river stages (within 1 foot of the landside levee toe) varies from 0.1 to 2 percent. At higher stages near the levee crest, the composite probability of failure varies from 0.2 to 6 percent. Failure modes of rapid drawdown, seismic, and under seepage were the most influential in the analyses. Based on review of levee conditions at the existing fragility curve sites, the levee height, riverside slope, and gradient landward of the landside levee toe strongly influence these failure modes.

Additional conclusions and geotechnical considerations regarding the condition of the levees and scope of this study are provided below.

- The original levees were constructed in the 1960s using dragline methods without compaction control. Subsurface soils within the levee prism typically consist of loose to medium dense silty sand that is vulnerable to piping.
- Based on review of the data provided, no breaches have been reported since original construction.
- Levee underseepage was one of the most influential failure modes in the fragility analyses. Areas of animal burrows, culvert penetrations, depressions and seepage were noted in periodic inspections and the King County Green River Levee Deficiency Action Plan. These deficiencies can result in shortened or preferential seepage paths leading to piping concerns. Anecdotal observations of seepage and piping were also noted within the Tukwila 205 study.
- As discussed above, relatively low probability of failure was calculated for each potential breach site. However, the results are based on quantitative stability and seepage analyses of the existing cross section geometry. Conditions such as piping due to animal burrowing, vandalism, vegetation weakening or strengthening, presence of seams of weak material, poor maintenance impeding detection of defects, and toe erosion or a scour-impacted cross section are not part of the analyses. Stability analyses of a revised levee section based on the effects of these conditions may result in greater probabilities of failure.
- Federal vegetation deficiencies were noted in several areas throughout the levee system including numerous large trees greater than 12-inch DBH (diameter at breast height). Vegetation considerations were not included in our geotechnical review.
- As discussed in Chapter 1 our scope of services focused on PL84-99 levees and review of geotechnical data provided in existing reports. No additional field explorations or site reconnaissance were included in the study.

- As noted previously, existing geotechnical data and the results of laboratory testing and stability analyses suggest relatively consistent conditions for the PL84-99 levee system. However, geotechnical data was not available for the Signature Point, Galli's, and Dykstra levees.
- Additional geotechnical assessment requirements to support the SWIF will be dependent on the level of protection goals and specific capital projects identified as part of the overall project recommendations.

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# ATTACHED FIGURES

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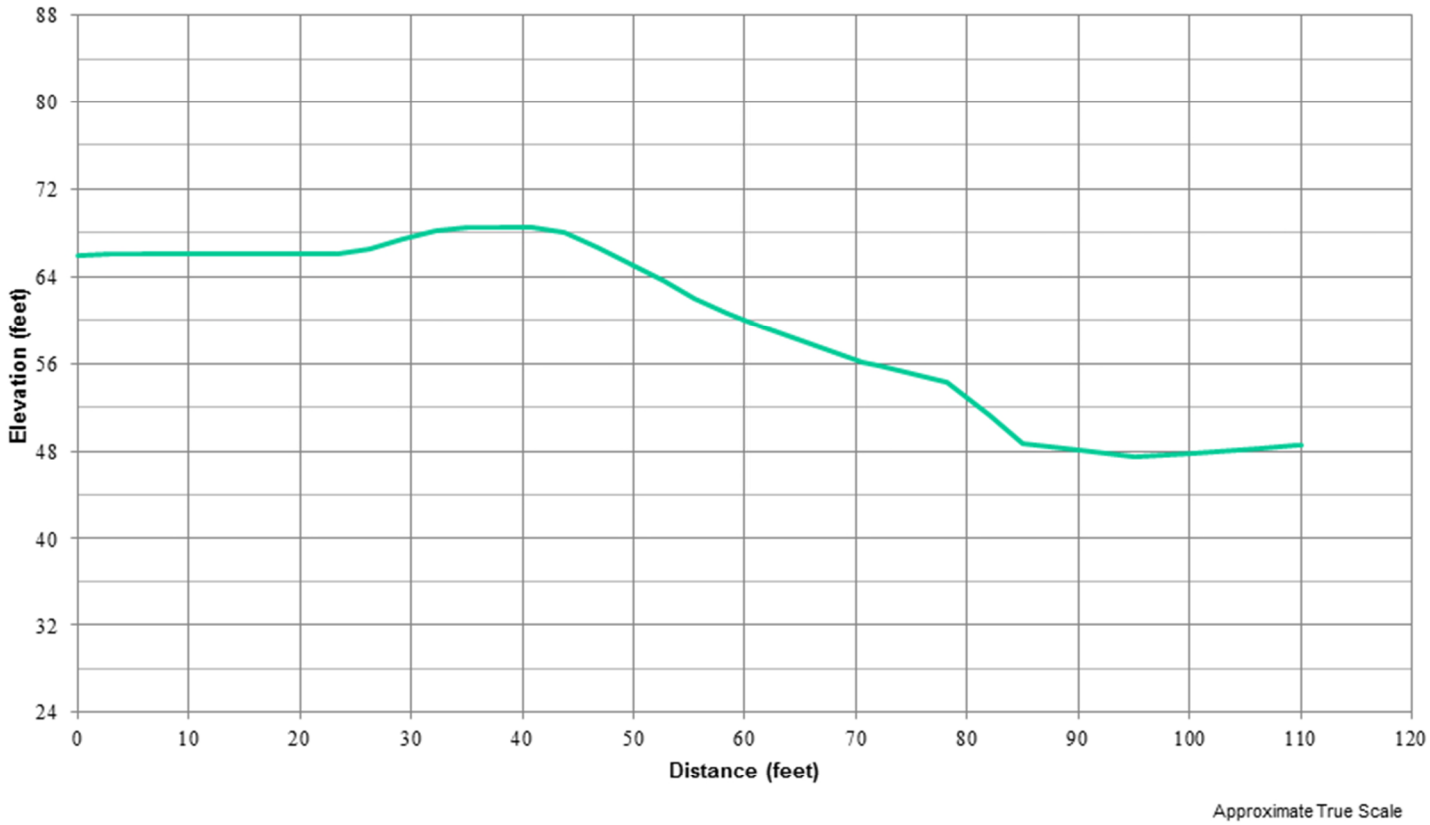
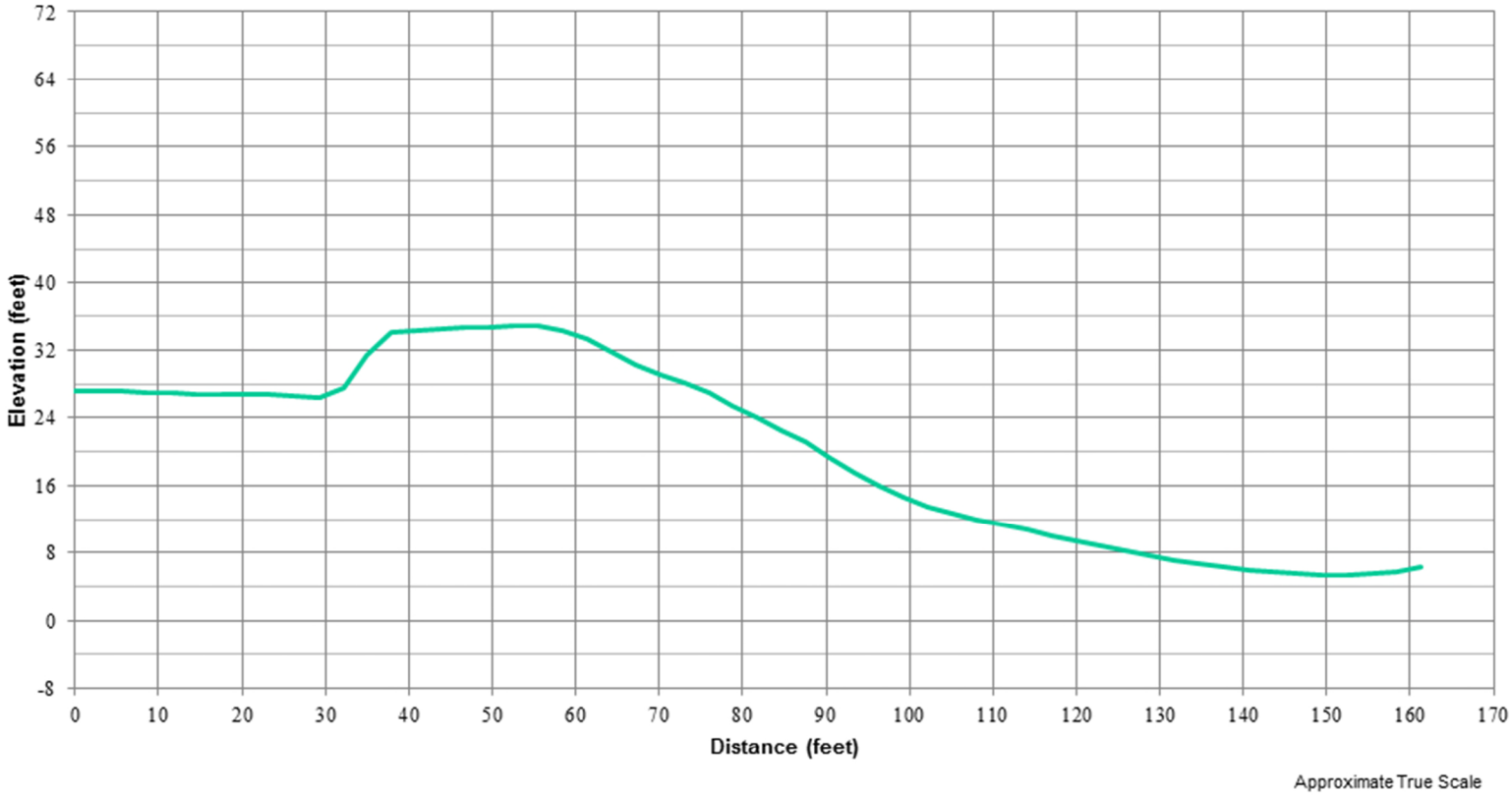



**Cross Section Geometry**
**Breach No. 1**
**Dykstra, LB 30.69**

Green River SWIF
King County, Washington

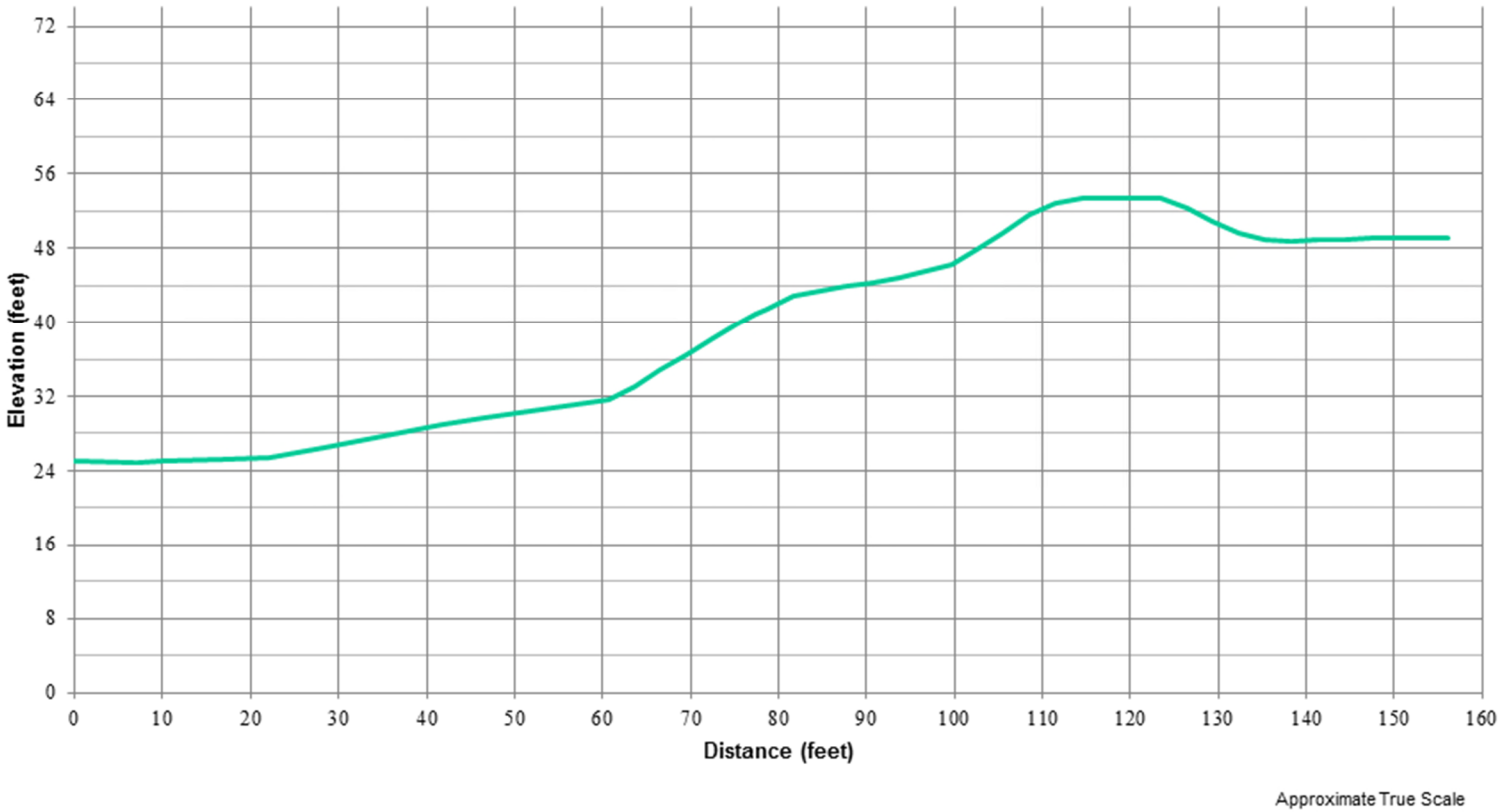
**GeoEngineers, Inc.** | **Figure 1**




**Cross Section Geometry**
**Breach No. 2**
**Tukwila 205, LB 14.83**

Green River SWIF
King County, Washington

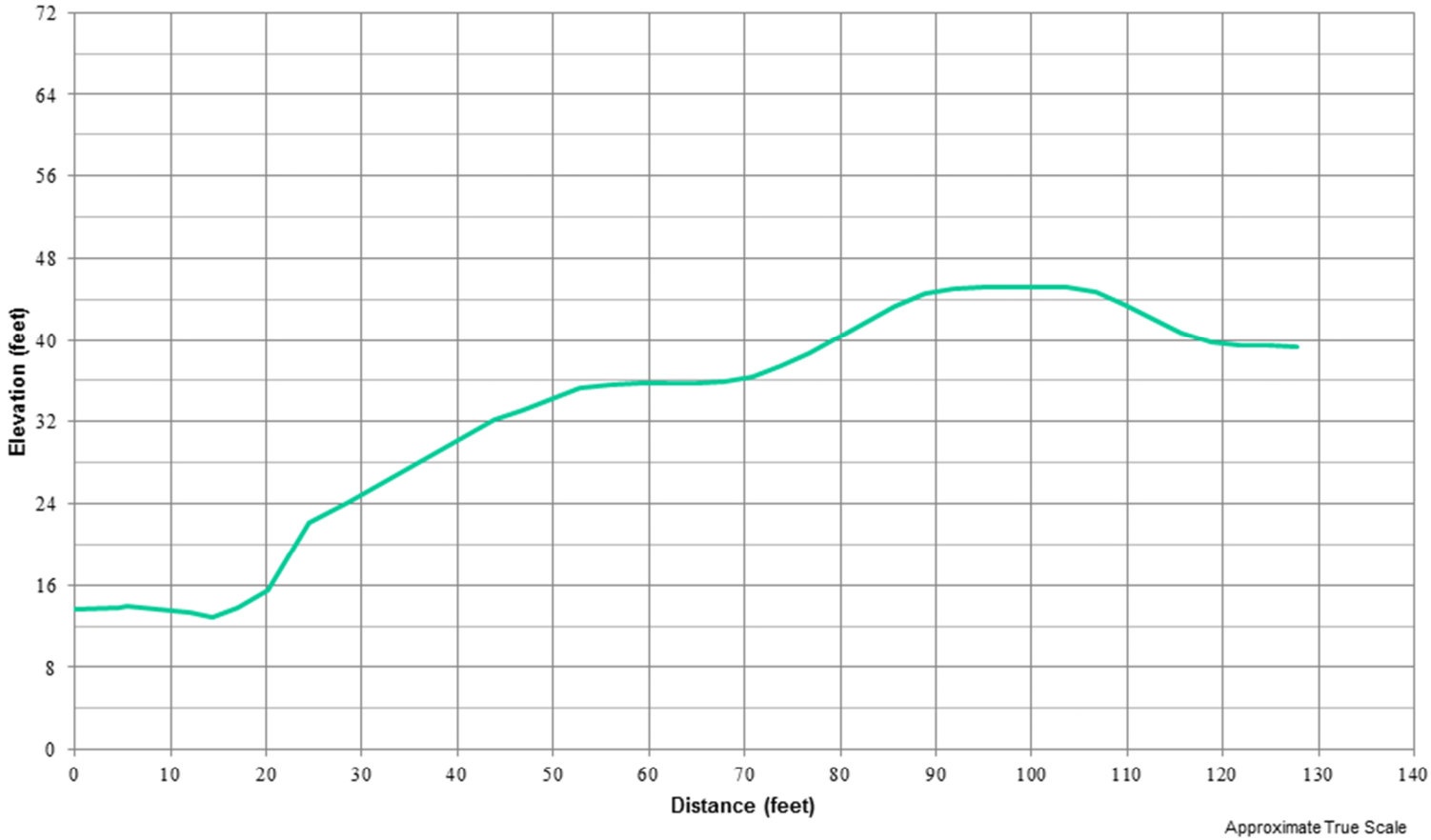
**GeoEngineers, Inc.** | **Figure 2**




**Cross Section Geometry**
**Breach No. 3**
**Horseshoe Bend, RB 25.50**

Green River SWIF
King County, Washington

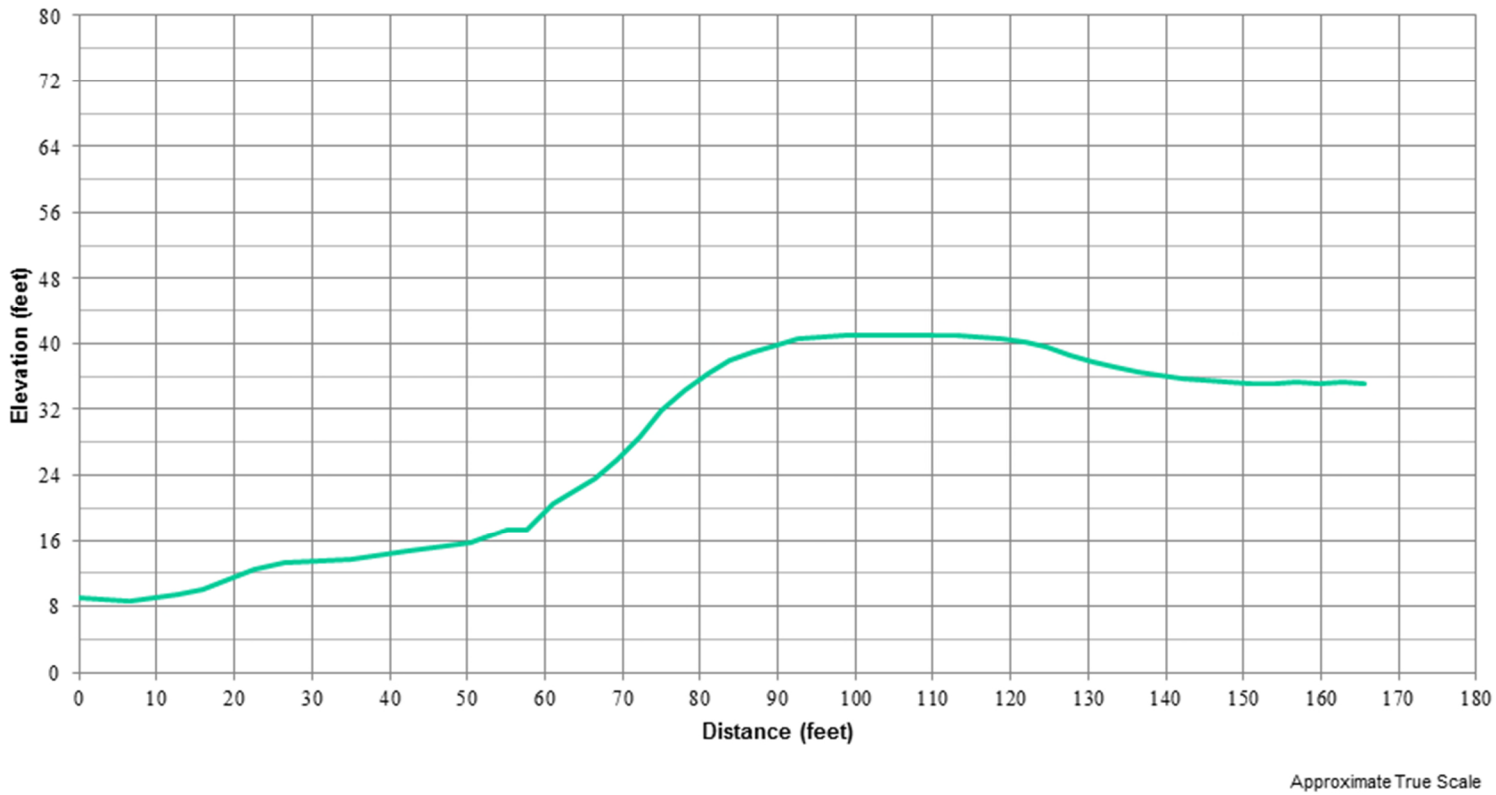
**GeoEngineers, Inc.** | **Figure 3**




**Cross Section Geometry**
**Breach No. 4**
**Meyer's Golf, RB 21.80**

Green River SWIF
King County, Washington

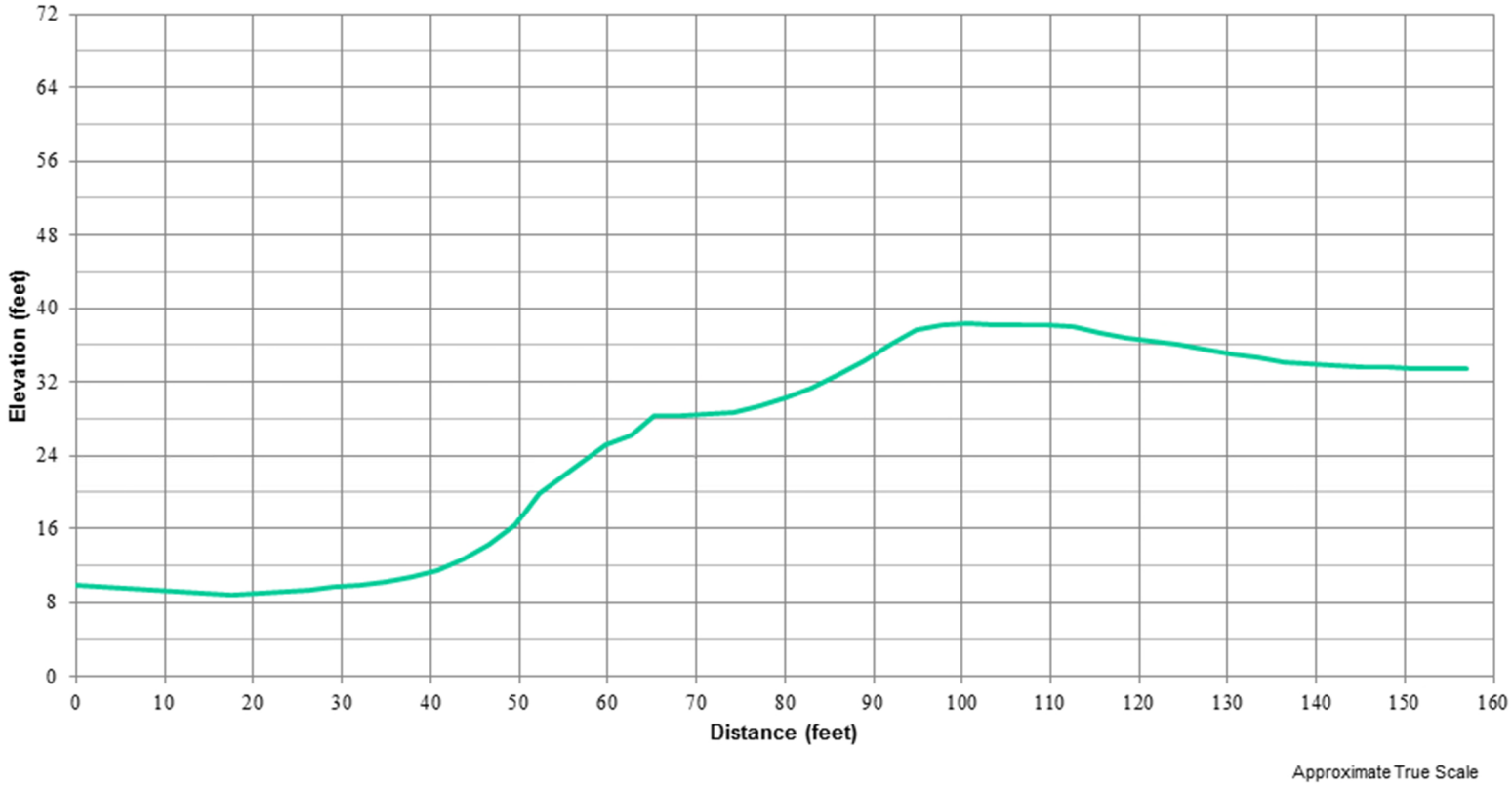
**GeoEngineers, Inc.** | **Figure 4**




**Cross Section Geometry**
**Breach No. 5**
**Lower Russell Road, RB 18.60**

Green River SWIF
King County, Washington

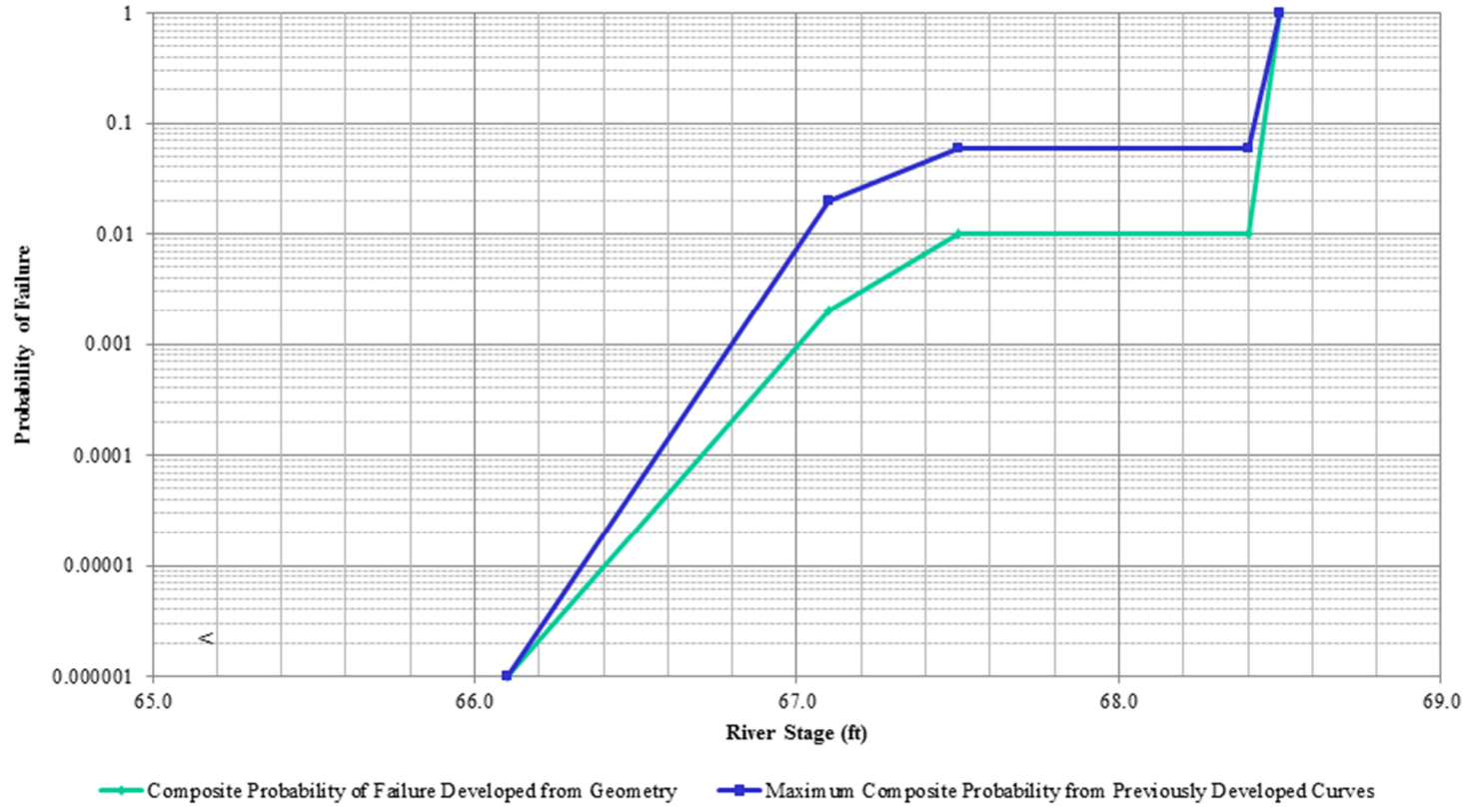
**GeoEngineers, Inc.** | **Figure 5**




**Cross Section Geometry**
**Breach No. 6**
**Briscoe-Desimone, RB 16.62**

Green River SWIF
King County, Washington

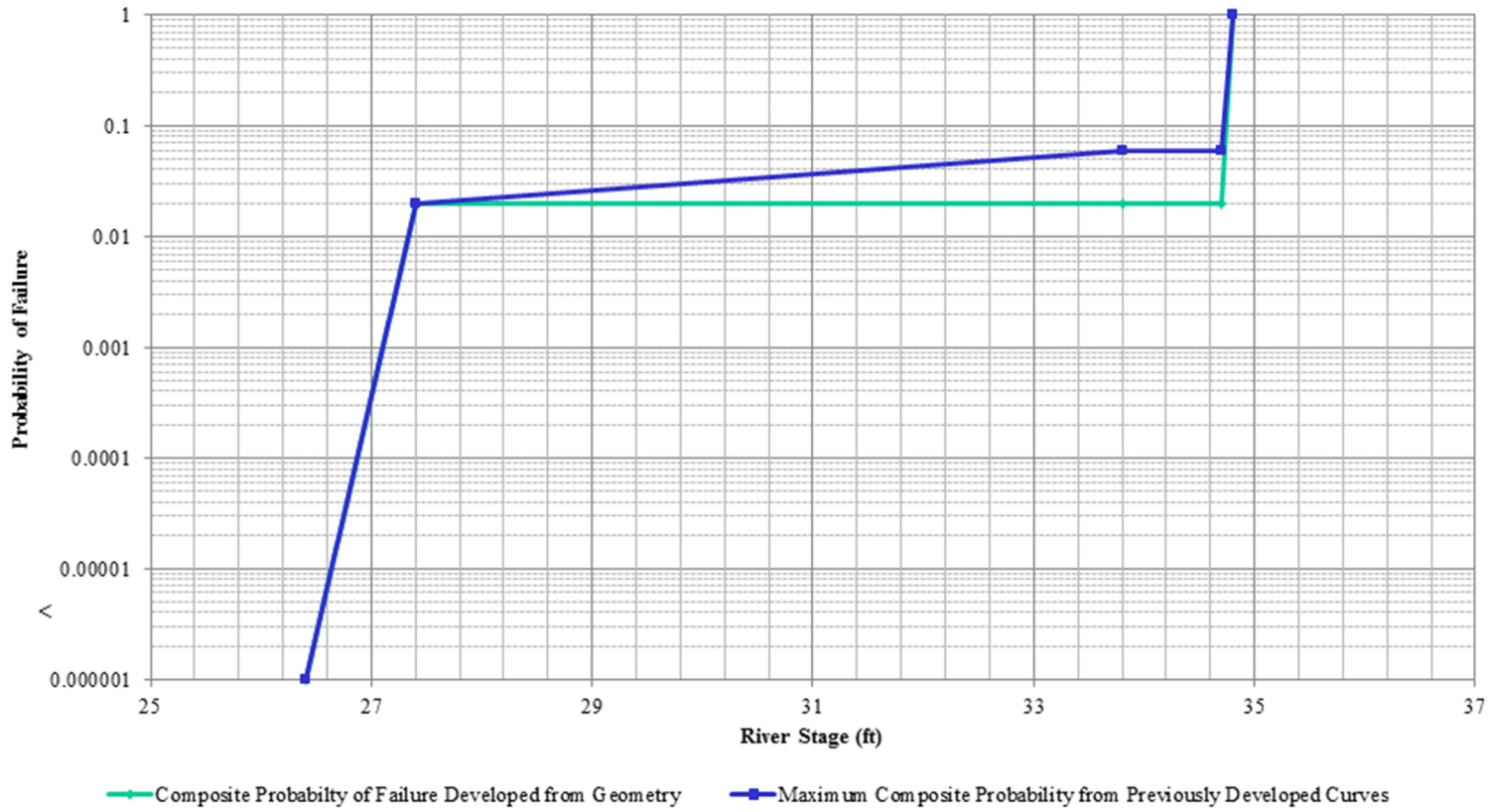
**GeoEngineers, Inc.** | **Figure 6**




**Stage Probability of Failure**
**Breach No. 1**
**Dykstra, LB 30.69**

Green River SWIF
King County, Washington

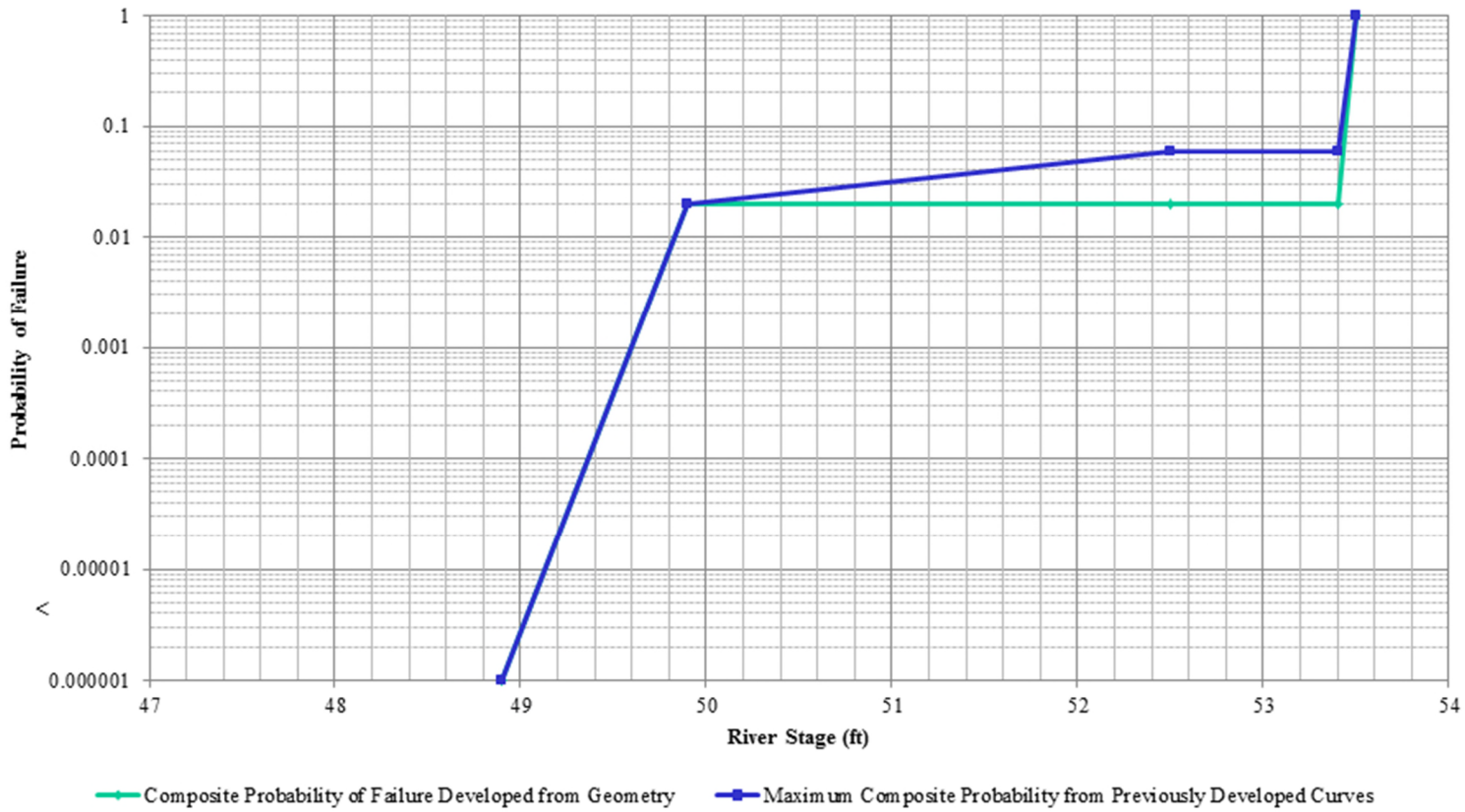
**GeoEngineers, Inc.** | **Figure 7**




**Stage Probability of Failure**
**Breach No. 2**
**Tukwila, 205 LB 14.83**

Green River SWIF
King County, Washington

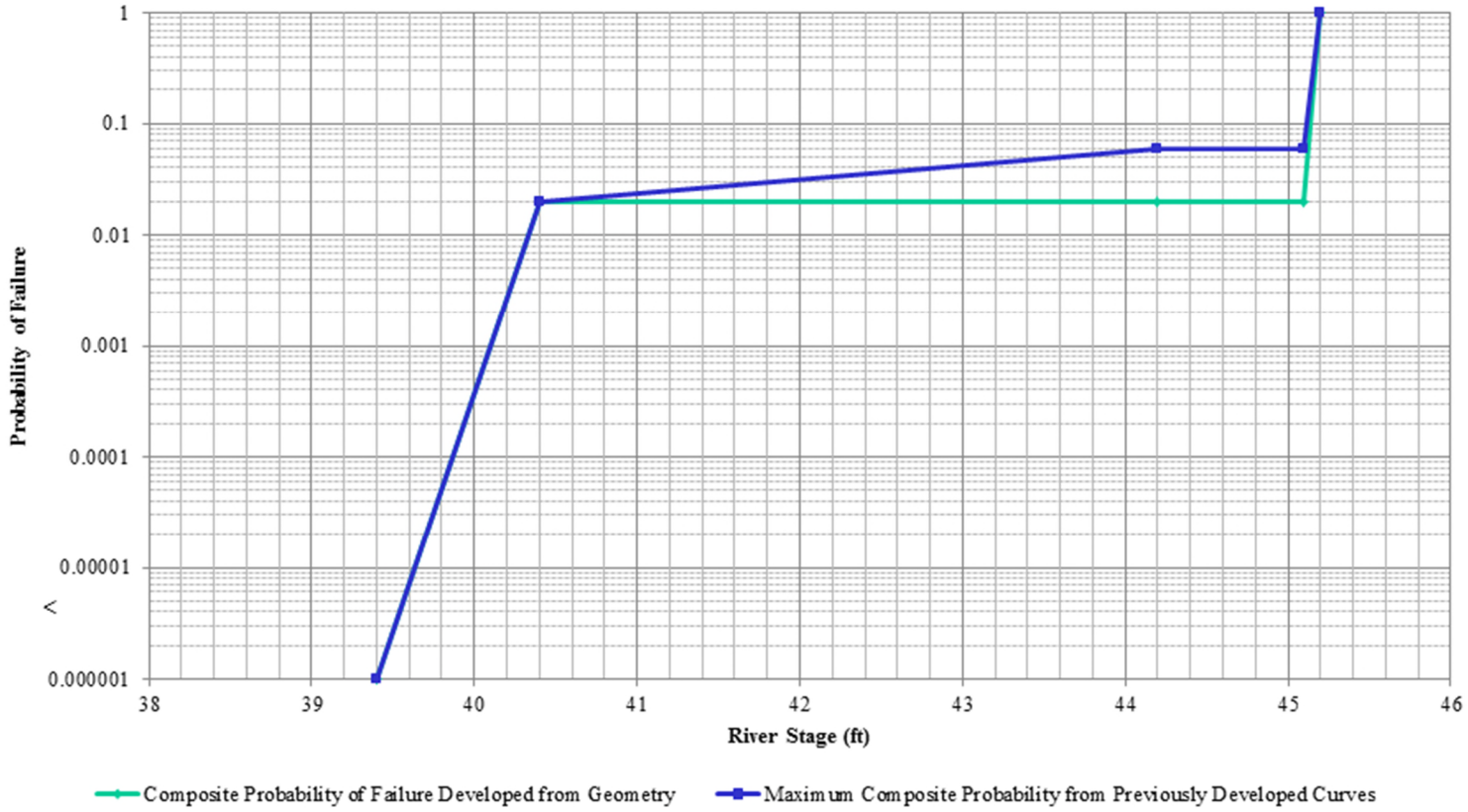
**GeoEngineers, Inc.** | **Figure 8**




**Stage Probability of Failure**
**Breach No. 3**
**Horseshoe Bend, RB 25.50**

Green River SWIF
King County, Washington

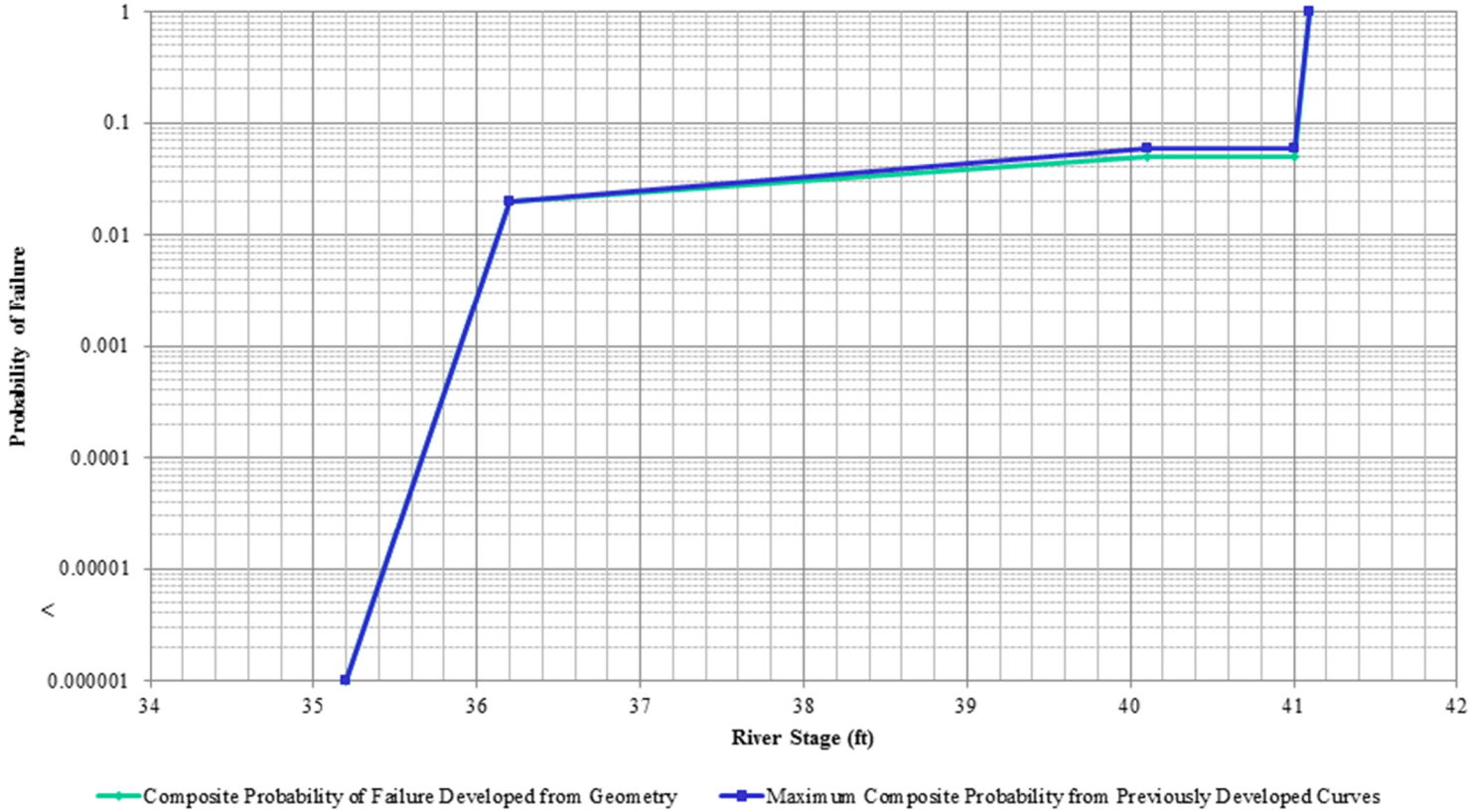
**GeoEngineers, Inc.** | **Figure 9**




**Stage Probability of Failure**
**Breach No. 4**
**Meyer's Golf, RB 21.80**

Green River SWIF
King County, Washington

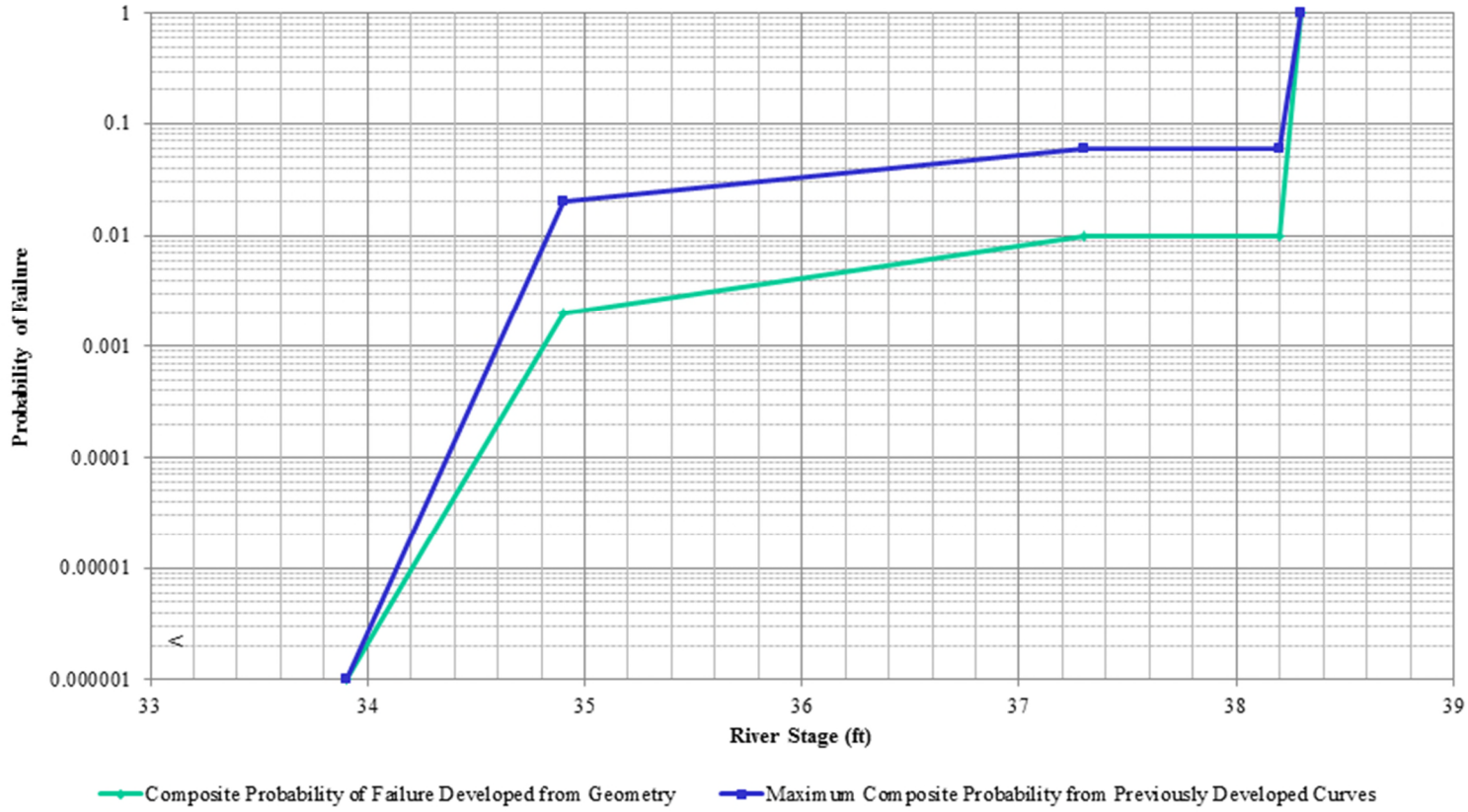
**GeoEngineers, Inc.** | **Figure 10**




**Stage Probability of Failure**
**Breach No. 5**
**Lower Russell Road, RB 18.60**

Green River SWIF
King County, Washington

**GeoEngineers, Inc.** | **Figure 11**




**Stage Probability of Failure**
**Breach No. 6**
**Briscoe-Desimone, RB 16.62**

Green River SWIF
King County, Washington

**GeoEngineers, Inc.** | **Figure 12**

King County

# GREEN RIVER, KING COUNTY, WASHINGTON
# SYSTEM-WIDE IMPROVEMENT FRAMEWORK (SWIF)

Photo Credit: King County

## ATTACHMENT D:
## HYDRAULICS TECHNICAL MEMORANDUM

**FINAL**

**MAY 2014**

King County

# GREEN RIVER SWIF

# CURRENT CONDITIONS REPORT

# HYDRAULICS TECHNICAL MEMORANDUM

**FINAL**

nhc
northwest
hydraulic
consultants

**MAY 2014**

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# 1. INTRODUCTION

## 1.1. PURPOSE AND SCOPE

This technical memorandum summarizes the objectives, methods, and results of the existing condition hydraulic modeling for the Green River System Wide Improvement Framework (SWIF). Hydraulic modeling is one element of the multi-discipline SWIF study focused on evaluating existing condition flood risks and vulnerabilities.

The Green River SWIF project area includes Howard Hanson Dam (HHD), located at river mile (RM) 64.5, and extends downstream to the upper Duwamish River, at approximately RM 5.5. The focus area of the SWIF is the upper Duwamish and Lower Green River floodplain, from approximately RM 5.5 to RM 32. Within the focus area there are approximately 18 miles of levees and 13 miles of revetments. Five PL 84-99 eligible levee systems between RM 11 and 32 are a priority for evaluation. The hydraulic analysis and focus of this technical memorandum is from RM 33 to RM 5.5 and also reflects operation of Howard Hanson for flood risk management.

The purpose of the existing condition hydraulic modeling and analysis task for the Green River SWIF project is to:

- Provide insight into flooding patterns, floodplain inundation depths and floodplain extents under various flood magnitudes and levee breach scenarios
- Estimate the channel conveyance capacity provided by the current levee system
- Provide floodplain inundation limits, depths, and durations for use in the flood risk assessment and economic modeling of flood damages

The hydraulic analysis maximized the use of existing models and data, which was facilitated by the extensive work conducted over the last eight years on the Lower Green River. This memorandum documents changes and updates to the pre-existing models used in this study. References for development of the pre-existing models may be found in Section 4.

## 1.2. SETTING

The Lower Green River valley begins at State Route 18 (SR18), at river mile (RM) 33.25, and extends downstream to the river's mouth in Elliott Bay. Place names and features described in the following narrative are shown in Figure 1-1. The river occupies a mostly undeveloped floodplain for about a mile downstream of SR18. Soos Creek, the largest tributary on the Lower Green River, enters from the north at RM 33.32. Nearing Auburn, the river enters the Auburn Narrows, where it is confined between the White River alluvial fan and the eastern valley wall. The USGS Green River near Auburn stream gage (12113000) is located in the narrows at RM 31.28. This gage serves as the flow regulation point for the HHD and is the standard location where Lower Green River flows are referenced.

The floodplain was divided into four economic modeling areas to assess flood impacts and damages. These damage areas follow logical divisions in levee systems and flood patterns and are shown as shaded areas in Figure 1-1. Damage areas boundaries do not follow the municipal borders of the city (or cities) used to name them.

The Auburn damage area is located on the left bank of the river beginning at RM 33.25. Below the Auburn Narrows a system of levees protect the left overbank from inundation by the Green River. These left bank levees end at RM 28.6, where the left bank becomes more natural except for sporadic levee segments, revetments, farm berms, and roads. These features provide limited protection until around RM 19, where a continuous levee system resumes. The floodplain falls away from the river to the west, where Mill Creek (Auburn) and Mullen Slough drain to the Green. Mullen Slough has an open connection to the Green River, which allows floods to utilize the Mill Creek/Mullen Slough floodplain. Available flood storage in this floodplain area provides significant attenuation during smaller floods.

The Kent/Renton damage area is located on the right bank of the river between RM 33.8 and RM 10.5. From RM 33.8 to RM 26.25 the right bank is a narrow floodplain corridor with a mix of natural high ground, valley wall, and short levee segments. RM 26.25 marks the beginning of the continuous right bank PL 84-99 levee system that extends to Interstate 405 (I-405) at RM 12.5. In this report references to the Kent/Renton damage area refer to the floodplain below RM 26.25 protected by the PL 84-99 levees. Mill Creek (Kent) and Springbrook Creek drain the eastern uplands and most of the damage area, eventually flowing north to the Black River pump station. The pump station, with a capacity of nearly 3,000 cfs, discharges into the Green River at RM 11.

The Tukwila damage area is protected by the Tukwila 205 levee, the only levee that has been accredited by FEMA in the past. The damage area is bounded by South 200$^{th}$ Street at the upstream end and I-405 at the downstream end. At RM 16.75, approximately 1,300 feet downstream of South 200$^{th}$ St., the Section 205 levee leaves the river and becomes a cross levee that runs westward to the valley wall. Between RM 16.75 and 17.25 the Segale South Tukwila development is rebuilding the river levee. The northern end of this levee ties into the Tukwila 205 levee and a new cross levee protects the area's southern boundary. The development is also filling most of the undeveloped floodplain within the levee protected area. In the past the Tukwila 205 cross levee forced all left bank floodplain flow back into the main channel; the new Segale cross levee will provide the same function when complete. A series of small pump stations drain this area.

The Duwamish damage area encompasses both sides of the floodplain below I-405 and extends downstream to RM 5. This portion of the river valley is narrower (generally 1/3 – 2/3 mile wide) than upstream areas and the valley wall occasionally encroaches on either bank. The risk of overbank flooding in this reach decreases steadily downstream, and by RM 5 the risk is minimal as the river becomes larger and increasingly tidally influenced. Below RM 5 all flows evaluated are entirely confined in the channel.

**Table 1-1: Left and Right Bank Conditions**

| Bank | Extents | Description |
|---|---|---|
| Right Bank | | |
| | RM 5.5-12.4 | Mix of natural high ground and revetments |
| | RM 12.5-26.25 | Continuous levee system, mostly in PL 84-99 program |
| | RM 26.25-33.8 | Mix of natural high ground, valley wall, and short levee segments |
| Left Bank | | |
| | RM 5.5-12.4 | Mix of natural high ground and revetments |
| | RM 12.4-16.7 | Tukwila 205 Levee |
| | RM 16.7-21.25 | Mix of levees, fill and natural high ground |
| | 21.25-28.6 | Mix of levees, farm berms, revetments and natural bank |
| | RM 28.6-30.9 | Continuous levee system, mostly in PL 84-99 program |
| | RM 30.9-33.8 | Mix of natural high ground, natural bank and revetments |

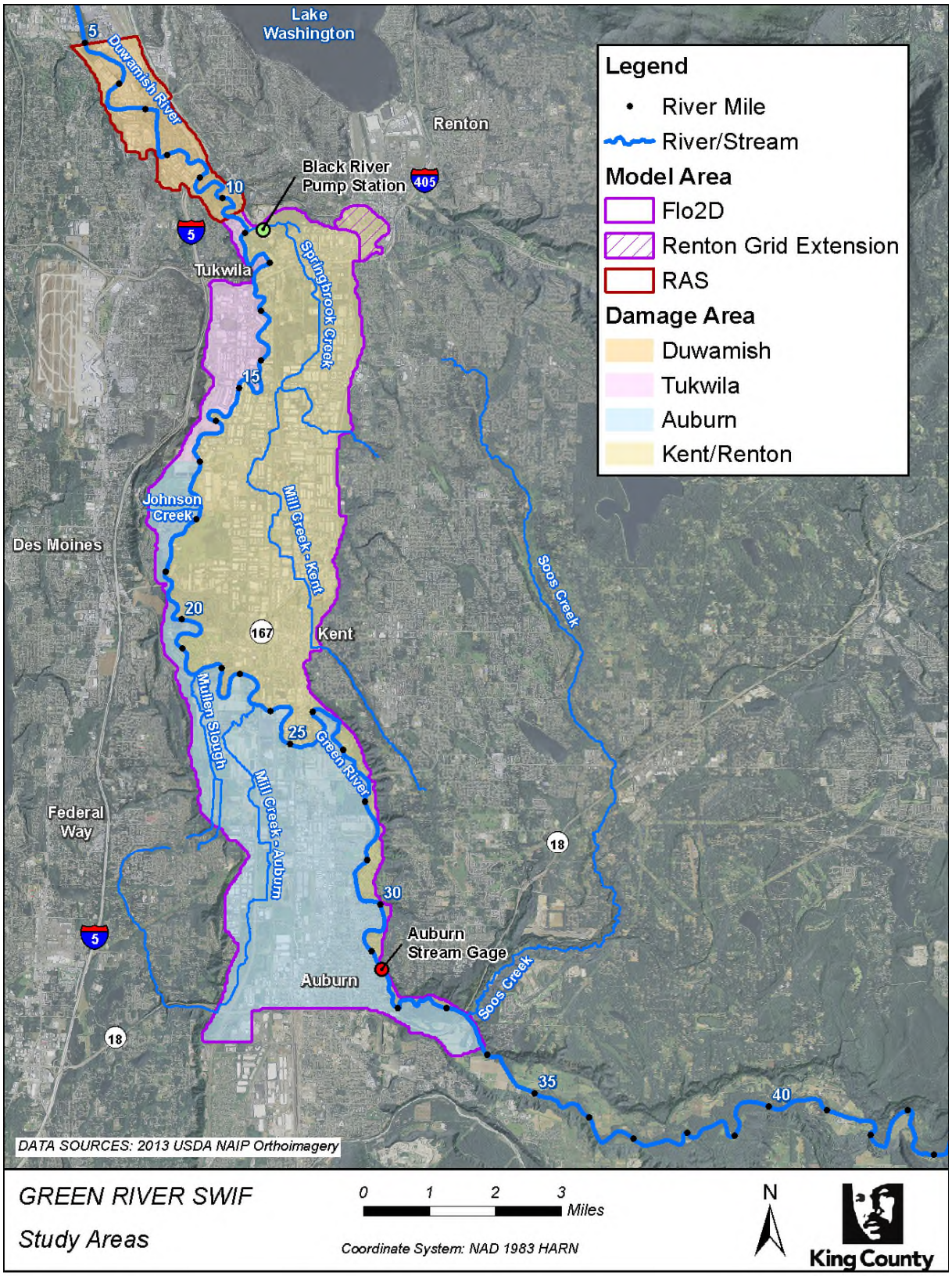


**Figure 1-1: Project Study Area**

# 2. HYDROLOGY

## 2.1. DESIGN FLOOD HYDROGRAPHS

Inflows for the hydraulic models were taken directly from the 2012 Seattle District Army Corps of Engineers (Seattle District) evaluation of design flood hydrographs for the Green River basin (Corps of Engineers 2012). The Seattle District study was undertaken specifically to support levee system analyses in the Lower Green River. A brief synopsis of the methods used in the study is given here.

Flood hydrographs for inflow to the HHD reservoir and local inflow between the dam and the Auburn gage were developed for the 50, 10, 4, 2, 1, 0.5 and 0.2 percent annual exceedance probability floods (commonly known by recurrence intervals as the 2, 10, 25, 50, 100, 200 and 500-year floods). The annual exceedance probability terminology will be used throughout this memo as it more clearly reflects uncertainty and risk and avoids the false perception that a 100-year return period event only happens once every 100 years.

For each flood event, uncertainty was captured by developing the high (5%) and low (95%) confidence limit (C.L.) hydrographs in addition to the median event, resulting in a total of 21 hydrographs. The confidence limit expresses the probability that a given flow will be exceeded for a particular flood event; for instance, the Low C.L. flow means there is a 95% likelihood that the true flow will exceed this value. The median is the 50% C.L. hydrograph, or the most likely flow to occur for a given flood probability. The 50% C.L. is implied when no C.L. is stated, for instance a '1% annual chance flood'. For clarity in this report flood events will be primarily referenced by their peak flow, with the annual exceedance probability (AEP) listed as a percentage. Confidence limits will be referred to as high, median, or low for the 5%, 50%, and 95% limits respectively. Table 2-1 is adapted from the Corps of Engineers (2012) report and lists all the flows and associated parameters developed.

HHD inflows were routed through the HHD reservoir using an operations model that followed procedures specified in the current Water Control Manual (Corps of Engineers 2011). HHD is operated to maximize available flood control storage during the flood season by keeping a low pool level. During floods, reservoir outflow is adjusted such that the total outflow plus local inflow between the dam and Auburn do not exceed the 12,000 cfs target flow at the Auburn gage. The 12,000 cfs target flow is kept as long as possible to minimize the time needed for evacuation of the reservoir. Regulated HHD outflow and local inflows between the dam and the Auburn gage were routed to the Lower Duwamish River using a calibrated HEC-RAS hydraulic model. The resultant routed flood hydrographs at the Auburn gage represented regulated flow conditions and comprised the basis of flows used for the current hydraulic analysis. The level of flood control provided by HHD can be seen in Figure 2-1, which plots both regulated and unregulated flows at various flood frequencies. During the median 1% AEP event, the unregulated peak flow at Auburn (unregulated inflow to HHD plus the local inflow between the dam and Auburn) is 45,900 cfs, while the median regulated peak flow at Auburn is 12,000 cfs. The dam can be operated to meet its 12,000 cfs regulation target flow up to around an annual exceedance probability of 0.71% (median 140-year flood). However, loss of regulation (flow exceeding 12,000 cfs) becomes a possibility by the 1% annual chance flood event, as seen in the high confidence interval curve.

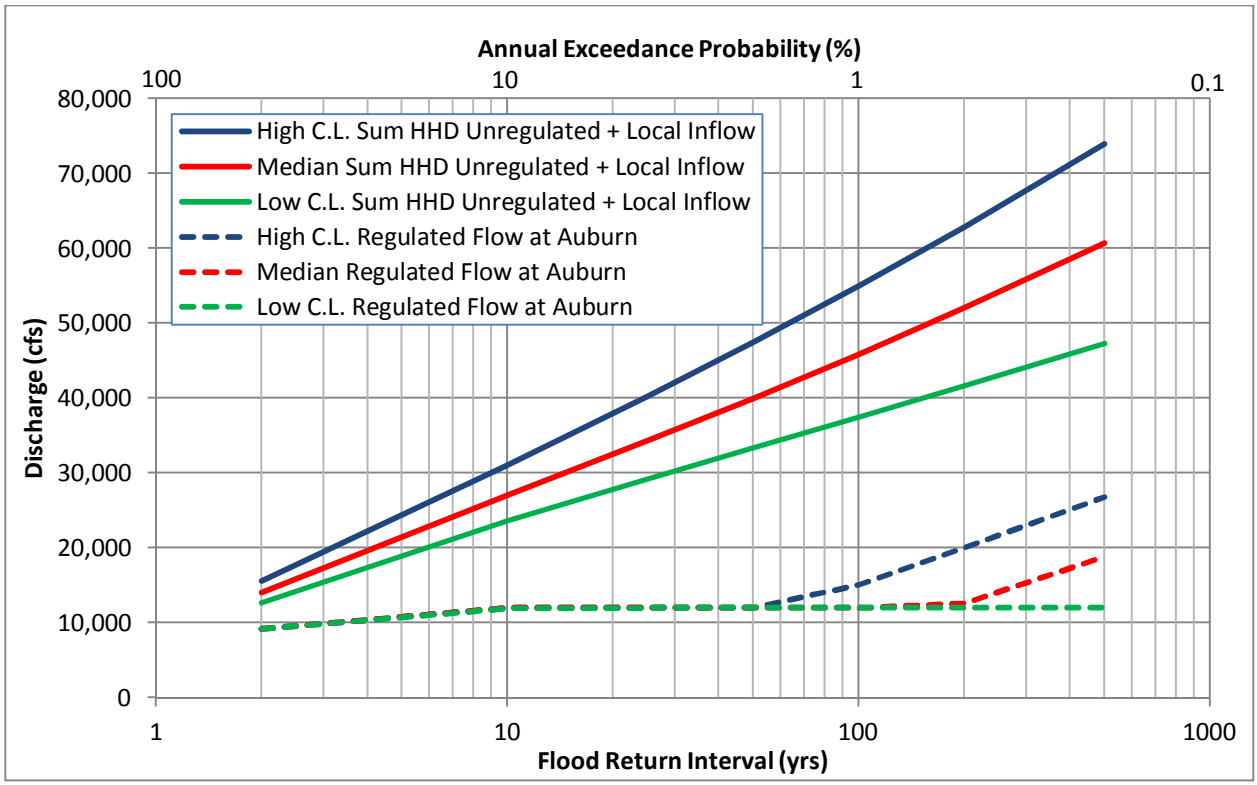


**Figure 2-1 Discharge vs Annual Exceedance Probability & Flood Frequency at Auburn (Corps of Engineers 2012)**

**Table 2-1: Simulated Regulated Flow at Auburn (USGS Gage 1211300) from Corps of Engineers (2012)**

| Flood Event | Confidence Level | Peak Flow (cfs) | Approximate Duration Above 12,000 cfs (days) | Approximate Duration Above 10,000 cfs (days) |
|---|---|---|---|---|
| 0.2% AEP Flood (500-yr) | Median | 18,800 | 3.8 | > 13 |
| | High Confidence Limit (5%) | 26,800 | 4.3 | >13 |
| | Low Confidence Limit (95%) | 12,000 | 0 | 11 |
| 0.5% AEP Flood (200-yr) | Median | 12,600 | 3.2 | >13 |
| | High Confidence Limit (5%) | 20,000 | 4.3 | >13 |
| | Low Confidence Limit (95%) | 12,000 | 0 | 9.4 |
| 1% AEP Flood (100-yr) | Median | 12,000 | 0 | 11 |
| | High Confidence Limit (5%) | 15,100 | 2.6 | >13 |
| | Low Confidence Limit (95%) | 12,000 | 0 | 7.5 |
| 2% AEP Flood (50-yr) | Median | 12,000 | 0 | 9 |
| | High Confidence Limit (5%) | 12,000 | 0 | 11.7 |
| | Low Confidence Limit (95%) | 12,000 | 0 | 6.3 |
| 4% AEP Flood (25-yr) | Median | 12,000 | 0 | 5.7 |
| | High Confidence Limit (5%) | 12,000 | 0 | 8.9 |
| | Low Confidence Limit (95%) | 12,000 | 0 | 4.5 |
| 10% AEP Flood (10-yr) | Median | 12,000 | 0 | 3.5 |
| | High Confidence Limit (5%) | 12,000 | 0 | 5.7 |
| | Low Confidence Limit (95%) | 11,900 | 0 | 2.8 |
| 50% AEP Flood (2-yr) | Median | 9,200 | 0 | 0 |
| | High Confidence Limit (5%) | 9,900 | 0 | 0 |
| | Low Confidence Limit (95%) | 9,200 | 0 | 0 |

## 2.2. Selection of Hydrographs for Hydraulic Modeling

The high degree of flow regulation provided by the HHD results in the majority of the regulated hydrographs having peaks at or very close to the 12,000 cfs target flow, although the total flood volumes vary widely (as shown by the duration data in Table 2-1). Hydrograph volume has an important effect on the extents and depths of flooding in the floodplain. Thus, although many of the regulated hydrographs have peak flow rates of approximately 12,000 cfs, the range in hydrograph volume needs to be considered so as to capture the full range of flood damages that can occur. Six hydrographs that represent the full range of flows and volumes evaluated by the Seattle District were selected for hydraulic modeling and economic analysis. The hydrographs are shown in Figure 2-2. In addition to these six, the median 91% AEP (1.1 year) event was modeled in HEC-RAS to provide a zero damage point for the economic analysis. Table 2-2 lists the selected hydrographs.

**Table 2-2: Selected Design Flood Hydrographs**

| Flood Event | Peak Flow at Auburn Gage (cfs) | Source | Comment |
|---|---|---|---|
| Median, 91% AEP | 3,500 | NHC | Steady inflow hydrograph |
| High C.L., 50% AEP | 9,900 | Corps of Engineers | Other 50% AEP events are similar; well below levee system crest |
| Low C.L., 10% AEP | 11,900 | Corps of Engineers | Lowest volume 12,000 cfs range peak event |
| Median, 0.5% AEP | 12,600 | Corps of Engineers | Highest volume 12,000 cfs range peak event |
| High C.L., 1% AEP | 15,100 | Corps of Engineers | -- |
| Median, 0.2% AEP | 18,800 | Corps of Engineers | Also used for the very similar High C.L., 0.5% AEP flood |
| High C.L., 0.2% AEP | 26,800 | Corps of Engineers | -- |

Inflow hydrographs for the FLO-2D hydraulic model (described below) were determined by extracting the routed Green River design flood hydrograph from the Seattle District HEC-RAS model at RM 33.25 and adding the corresponding Soos Creek hydrograph. Flows simulated by the FLO-2D model at the Auburn gage differ slightly (about 1% for the largest flood) from those routed through the Seattle District HEC-RAS model. For consistency with the Corps of Engineers' Design Hydrograph report (2012), the published flows at the Auburn gage are referenced in this report.

No local inflows below the Auburn gage were calculated as part of the Seattle District' Design Hydrograph report. For the SWIF study, local inflows from the 180$^{th}$ to 200$^{th}$ St Levee Setback study (Tetra Tech 2011) and the Lower Green River Floodplain Mapping Study for (NHC 2008) were used. Local inflows below Auburn include Mill Creek (Auburn) and various small stormwater pump stations. These local inputs are minor compared to the Green River flows. Local inflows were added riverward of the levee system. There is no simulation of interior drainage landward of the levees in the FLO-2D model. Local inflow from Mill Creek (Kent) and Springbrook Creek, in the Kent/Renton damage area, was accounted for by reducing the capacity of the Black River pump station from 2950 cfs to 2650 cfs. This 300 cfs reduction equates to the 9-day 1% AEP flow from local drainage as estimated in the Lower Green River Floodplain Mapping Study (NHC 2008). This approach allocates 300 cfs to local inflow that the pump station must discharge, and allows the remaining pump station capacity to be used for evacuation of Green River floodwaters that have entered the damage area through levee overtopping or breaching.

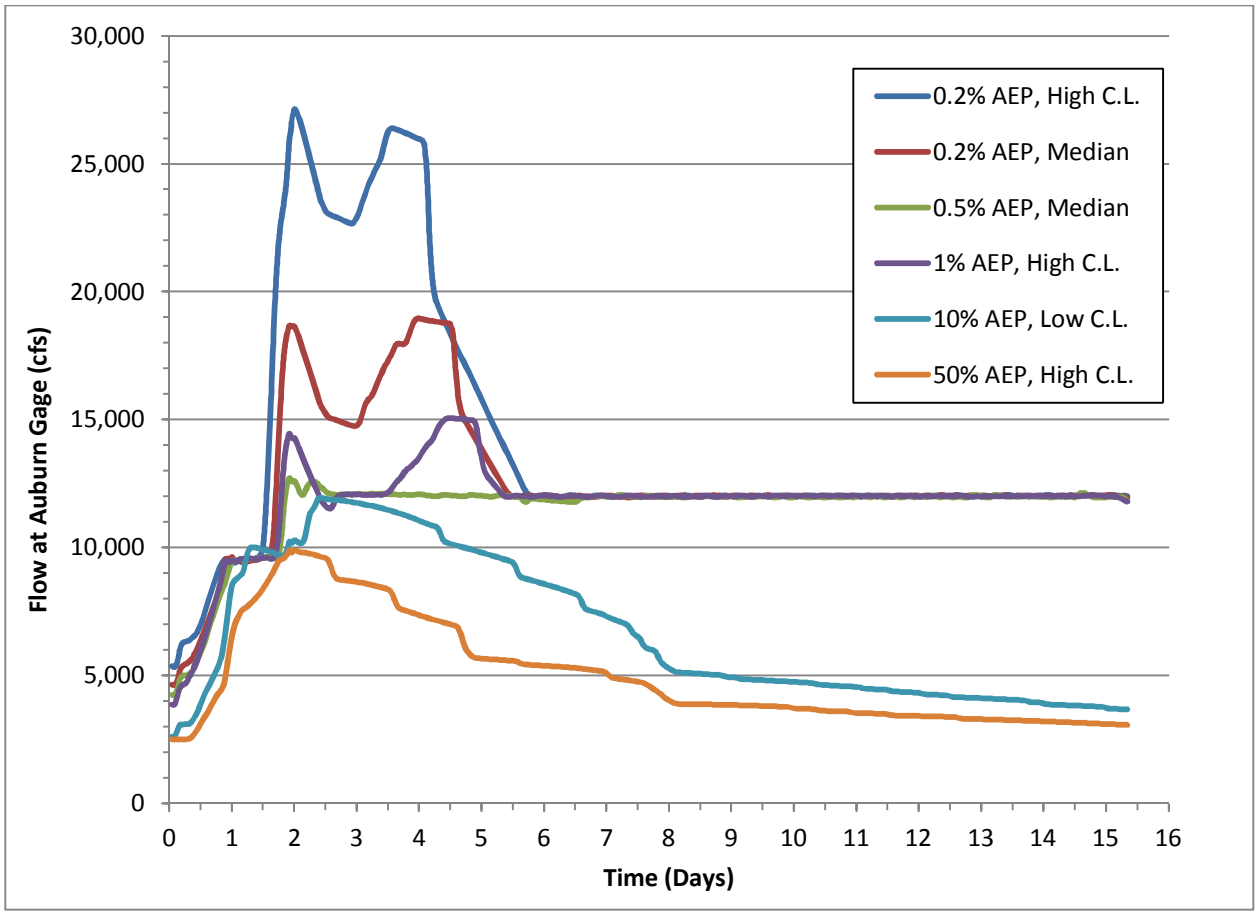


**Figure 2-2 Selected Design Flow Hydrographs**

# 3. HYDRAULICS

## 3.1. MODEL BACKGROUND AND HISTORY

The Green River has had extensive hydraulic modeling conducted in the last eight years, allowing the use of existing models to form the basis of the current analyses of existing conditions. In 2006, NHC began development of HEC-RAS models of the middle Green River (NHC 2007), as well as both HEC-RAS and FLO-2D models of the Lower Green River (NHC 2008). This modeling was used to develop floodplain maps to support an appeal of preliminary maps issued by FEMA. The FLO-2D model was also used to investigate levee breach risk and economic damages in a manner similar to that in the current SWIF study (Shannon & Wilson 2009). In 2009, both models were extended upstream to evaluate numerous scenarios related to concerns regarding the HHD dam. These concerns were revealed during the 2009 flood when the reservoir reached a record peak stage and increased levels of turbidity were observed in discharge from the vertical drainage wells. The HEC-RAS model was extended from RM 44 to the dam at RM 64.3, and the upstream end of the FLO-2D model was extended to the SR18 Bridge at RM 33.25. The models have seen continued use since that time, including analysis of numerous City of Kent levee accreditation projects, and levee alternatives analyses and design for King County (Tetra Tech 2011).

Both the HEC-RAS and FLO-2D models were used for the current study, with modifications described below. For the current study, the FLO-2D model extends between RM 33.25 and RM 10, while the HEC-RAS model extends between RM 64.3 and RM 3.8.

## 3.2. Model Limitations

At the time of initial model development around 2006, the best available information indicated that the HHD could fully control floods as large as the 0.2% AEP event. Allowing for operational uncertainty in dam operations resulted in the estimated 1% AEP and 0.2% AEP peak flows at the Auburn gage to be 12,800 and 13,500 cfs, respectively. Since regulation began at HHD in 1961, the largest observed flow at Auburn is 12,400 cfs, during the 1996 flood. No levees overtopped or were breached during this event. As a result, the models were constructed with the understanding that the largest flows to be modeled were less than 14,000 cfs. Calibration data was only available for floods of 12,400 cfs and lower. Additionally, model calibration was limited to the Green River channel portion of the models. While the models have proven robust for simulating discharges ranging between summer low flow to an unregulated 60,000 cfs scenario, there have been no floods that inundated areas protected by levees to provide any calibration or validation of the accuracy of the overbank simulations. In addition, the analysis does not account for either increased peak flows or sea level rise that is expected due to climate change in the future.

## 3.3. HEC-RAS Model

HEC-RAS models used in this study are created from modeling developed for the Design Hydrograph report (Corps of Engineers 2012). The Corps model was based on the earlier NHC models developed for King County. The Seattle District converted NHC's model to run in unsteady mode and with some modifications to simulate higher flows and improve stability. Upstream of the Auburn gage, the model includes the entire floodplain; however, downstream the model only includes the main channel. This is equivalent to assuming there are levees high enough to prevent overtopping at any simulated flow. One consequence of this assumption is that the Mullen Slough/Mill Creek (Auburn) floodplain, which provides significant storage and flow attenuation for the lower range of floods, is not represented in the HEC-RAS model.

### 3.3.1. Modifications

NHC clipped the full model at RM 12.7 to create a separate model of the river encompassing only the reach downstream of I-405. This clipped model was used to develop floodplain inundation mapping for the area downstream of the FLO-2D model limits. Additional detail was added to the clipped model by extending cross-sections and adding storage areas to span the full width of the floodplain. No floodplain extension was completed below RM 5 where preliminary testing showed that all flows were fully confined within the main channel. The lower boundary condition for the clipped HEC-RAS model remained a fixed water surface elevation of 8-ft (NAVD), representative of a high tide in Elliott Bay. The upper boundary condition was outflow from the FLO-2D model. Subsequent references to the "clipped" HEC-RAS model refer to the model described above. The Seattle District complete HEC-RAS model is referred to as the "full" model.

# 3.4. FLO-2D Model

The FLO-2D model was used to analyze flooding from RM 33.25 to RM 10. FLO-2D Version 2007 (FLO-2D 2007) was used to avoid potentially extensive changes in model configuration files.

## 3.4.1. Modifications

### 3.4.1.1. Levee Improvements

Model updates were necessary to reflect recently completed flood control projects along the Lower Green River. Several future levee improvement projects were also included in the existing conditions model. Plans for each project were obtained and incorporated into the FLO-2D model geometry.

**Table 3-1: Flood Control Project Updates to FLO-2D Model**

| Project Name | River Mile Extents | Project Status and Construction Date | Model Updates |
|---|---|---|---|
| Reddington Setback Levee (LB) | 28.6-29.5 | Constructed 2013 | Levee alignment, elevation, channel cross-sections |
| Reddington Extension (LB) | 28.2-28.6 | 90% Plans (2015 or 2016) | Levee alignment, elevation |
| Horseshoe Bend Levee (RB) | 26.0-26.2<br>24.25-24.50 | Constructed 2012-13<br>Constructed 2012-13 | Levee alignment, elevation |
| Foster Park Levee (RB) | 23.8-24.05 | Constructed | Levee alignment, elevation |
| Hawley Road Levee (RB) | 23.2-23.3 | In construction (2012-2014) | Levee alignment, elevation |
| Upper Russell Road Levee (RB) | 20.1-20.4<br>19.5-19.8 | 100% Design (2014-2015)<br>Constructed 2013 | Levee elevation |
| Boeing Levee (RB) | 17.0-17.2 | Constructed 2013 | Levee elevation |
| Briscoe-Desimone Levee (RB) | 16.9-17.0<br>16.0-16.4<br>15.45-15.6<br>14.5-14.6 | 30% Design (2015)<br>100% Design (2014)<br>100% Design (2014)<br>30% Design (2015) | Levee elevation, channel cross-sections |
| Segale/Tukwila Development (LB) | 16.7-17.3 | In construction (2012-14) | Levee alignment, elevation, channel cross-sections, floodplain fill |

### 3.4.1.2. Downstream Boundary Condition

The FLO-2D model's downstream boundary was modified to allow both channel and floodplain outflow, making it consistent with the clipped HEC-RAS model's floodplain spanning cross-sections. A rating curve generated from the clipped HEC-RAS model was used to define the downstream FLO-2D boundary.

## 3.4.2. Preliminary Investigations

Quality assurance checks on modeling of levee crest elevations and bridges were conducted. Multiple FLO-2D runs were then used for testing purposes to help guide the team's decision making process. These test simulations were not used in the economic damage assessment but are described below for completeness.

#### 3.4.2.1. Levee Crest Elevations

Accurate levee crest elevations are an important aspect of determining flood patterns on the Lower Green River. To validate these elevations, recently provided 2013 LiDAR was compared against the 2006 model geometry. All structures coded as levees in the FLO-2D model, including river levees and railroad and highway embankments, were evaluated. The median difference between model and LiDAR elevations for these structures was 0.15 feet. Of the 6091 points compared, 61% were within 0.5 feet and 80% were within 1 foot. A further check was provided by visually comparing left and right bank LiDAR and model levee profiles. This check indicated that large differences were generally the result of deliberate model updates. Examples include intersections on embankments, under and overpasses, and areas with floodwalls not detected by the LiDAR. This comparison confirmed the accuracy of levee elevations represented in the FLO-2D model.

#### 3.4.2.2. Bridge Effects

At flows around 12,000 cfs, which is the flow magnitude that the original HEC-RAS and FLO-2D models were developed to simulate, the 28 Green River bridges within the FLO-2D model domain have only negligible backwater effects. All the bridges are clear or near-clear span structures and the bridge approaches do not constrict the channel. The original HEC-RAS model includes all 28 of the bridges, whereas the original FLO-2D model does not. The necessity of adding bridges to the FLO-2D model was investigated for the current study. This was based on concerns that the higher flows simulated for the current study could result in significant bridge backwater effects that the FLO-2D model would fail to capture. Therefore, a comparison of HEC-RAS and FLO-2D water surface profiles was undertaken to evaluate the issue. Prior studies had shown the two models gave similar results at flows around 12,000 cfs. This was expected given that the primary calibration events for both models were two floods of this magnitude and that the bridges have negligible backwater effects at this flow. Comparison between the two models therefore focused on flows of 15,100 cfs and greater.

For the comparison, the FLO-2D model was modified to only include the mainstem channel in order to mimic the channel-only full HEC-RAS model. Both models were run with a steady-state flow rate until water surface elevations stabilized so as to eliminate hysteresis effects from the comparison. Water surface elevations simulated by the FLO-2D model were consistently higher than those simulated by the HEC-RAS model for both the 15,100 and 18,800 cfs runs; however, agreement was closer for the latter. For the 26,800 cfs run, water surface elevations simulated by FLO-2D were lower than HEC-RAS below RM 29 and higher above (Figure 3-1). The likely explanation is evident in the bridge outputs from the HEC-RAS model, which showed that only one of the bridges was in pressure flow below 18,800 cfs, but all were in pressure flow at 26,800 cfs. It is only at this higher discharge that bridge backwater effects are readily apparent in the water surface profile as seen at RM 24.

There were also concerns with adding bridges to the FLO-2D model due to known issues with the simplistic (compared to HEC-RAS) bridge calculation routines. Bridges are represented as single-function rating curves in FLO-2D. That is, for a given upstream stage the model will allow a certain amount of flow through the bridge, without regard to the stage downstream of the bridge or any other factor. This approach, by definition, will eliminate the known flow hysteresis in the Lower Green River system. In addition, in areas of dense bridge spacing, the flow in the channel becomes governed by a series of rating curves rather than the equations of motion (i.e., the model becomes over-constrained). Finally, close bridge spacing can cause model instability if there are small incompatibilities in the rating curves from one bridge to the next.

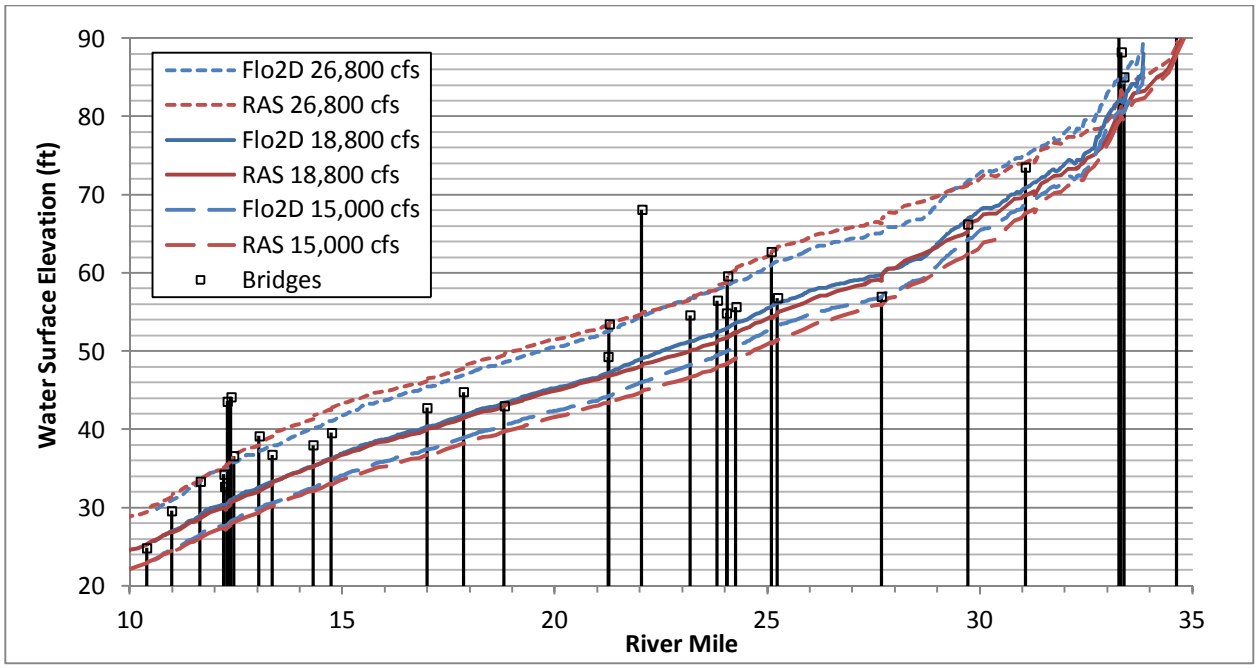


**Figure 3-1 HEC- RAS and FLO-2D Water Surface Profiles Under Confined Channel and Steady Flow Conditions**

Based on the modeling results it was determined that bridges should not be added to the FLO-2D model. FLO-2D results are equal to or conservatively high as compared to HEC-RAS results for all but the 26,800 cfs (High C.L., 0.2% AEP) flood. In the 12,000 cfs range where the majority of design hydrograph flows occur, the model has been successfully calibrated to observed high water marks without bridges.

#### 3.4.2.3. Effects of Flood Volume on Depth and Inundation

As shown in Table 2-1, 14 of the 21 design hydrographs have peak flows at or near 12,000 cfs, but it is noted that the total flood volumes vary widely, as indicated by the duration metrics in Table 2-1. Hydrograph volume has an effect on the extents and depths of flooding in the floodplain. Thus, although these 14 hydrographs all have approximately equivalent peak flow rates, the range in hydrograph volume needs to be considered so as to capture the full range of flood damages that can occur. Preliminary modeling of low and high volume near-12,000 cfs peak flow hydrographs was conducted to determine if only one or two events in this range could be used to characterize flood depths and inundation extents. Simulation results for the low volume 11,900 cfs flood (Low C.L., 10% AEP) and high volume 12,600 cfs flood (Median, 0.5% AEP) with preliminary levee breaches into the Kent/Renton damage area showed that the larger volume event inundated an additional 1.1 square miles of floodplain, and the average depth of inundation was 0.5 feet greater. Given these significant differences, both events were selected to bracket the range of damages resulting from the cluster of flood events characterized with peak flows of approximately 12,000 cfs.

#### 3.4.2.4. Levee Breach Location Selection

A key component of the existing condition evaluation included a levee failure analysis which required consideration of potential breach locations, levee overtopping, and overbank flooding throughout the system. Potential levee breach locations were informed by geotechnical, geomorphic, hydraulic and economic factors. Geotechnical assessment focused on the PL 84-99 levee systems and synthesis of previous work to identify 15 potential breach locations. These site specific locations were screened by the integrated Consultant-King County project team with 6 locations being identified for further

consideration. Geomorphic considerations in support of the levee failure analysis included an assessment of incision points throughout the focus area to pinpoint areas of concern. Economic considerations included land use and development patterns. Hydraulic considerations were also included and are outlined below. Based on compilation and integration of the above parameters, four levee failure scenarios were identified by the project team and are shown in Table 3-2. In addition, an overtopping only scenario without levee failure, which is referred to as the overtopping-no-breach scenario was simulated. The scenarios are intended to represent the range of possible failure situations that might occur under existing conditions. The results will be combined in the economic assessment to arrive at a system wide expected annual damage/impact figure.

Selection of levee breach locations was a multi-disciplinary effort described in full in the accompanying SWIF Economics Technical Memorandum. FLO-2D model results were used as one component in the selection process, primarily to ensure that the selected breach locations would be representative of overall flooding patterns.

Prior model results involving breach simulations throughout the Kent/Renton damage area were used to gain an understanding of what areas would inundate as a result of a breach in a given segment (NHC 2010). In general, the floodplain in this damage area slopes away from the river and to the north. As a result, areas closer to the river and farther upstream tended to be inundated only by breaches located nearby. In contrast, areas away from the river, especially in the northeast portion of the damage area, incurred inundation from any breach simulated. GIS was used to map the number of different breaches that inundated a given floodplain area. Areas of extensive inundation with a single breach source were identified and used as one parameter in the breach selection process.

Another breach location decision was whether the Briscoe-Desimone or Meyers Golf Course levee area should be selected for the second breach location into the Kent/Renton damage area (the Horseshoe Bend Levee being the site of the first selected breach into this area). Both locations were simulated with a breach and results compared. The simulations showed the Meyers Golf Course breach inundated a large upstream area as well as most of the area the Briscoe-Desimone breach flooded. The Meyers Golf Course breach was selected in large part based on this result.

**Table 3-2: Model Breach Locations**

| Breach Name | Breach River Mile | River Bank (looking downstream) | Breach Damage Area/Community |
|---|---|---|---|
| Tukwila | 14.9 | Left | Tukwila |
| Meyers Golf Course | 21.7 | Right | Kent/Renton |
| Horseshoe Bend | 25.4 | Right | Kent/Renton |
| Dykstra | 30.6 | Left | Auburn |

#### 3.4.2.5. Levee Breach Independence runs

Once the four breach locations were selected one additional set of runs was conducted to verify the hypothesis that breaches at the Dykstra and Tukwila 205 locations were hydraulically independent – that results in one damage area did not depend on whether or not a breach occurred in the other damage area. Simulations with a single breach at either location and with both breaches were run and results compared. Differences between the two simulations of the two levee breaches were negligible, confirming hydraulic independence. This enabled the two breaches to be run in a single simulation, reducing the number of scenarios required from five to four.

## 3.5. Levee Breach Modeling

The Simplified Breach Analysis (SIMBA) levee breach model (Temple et al 2006) was used to investigate rates of breach growth and size. This model was used in previous studies on the Green River for similar purposes (Shannon & Wilson 2009; Tetra Tech 2011). Key input data included existing levee cross-sections, simplified hydraulic data extracted from the FLO-2D model and the soil parameters for the levee prism, including erodibility. The erodibility value used was taken from the 180$^{th}$ to 200$^{th}$ Street Levee Setback study (Tetra Tech 2011) and is in the upper end of the range reported in the literature, reflecting the uncertain construction methods of some of the existing levees.

Initial SIMBA breach growth rates were similar to those calculated in prior studies, but total breach widths were higher. Examination of results showed that SIMBA predicted continued breach growth, albeit at a lower growth rate, during the latter part of most design flood hydrographs when flows were being regulated to 12,000 cfs for long periods of time, as shown in Figure 3-2. In contrast, previous work used hydrographs with flows quickly dropping below 10,000 cfs, ending flow through the breach and consequent breach growth. As such, the significantly higher breach widths predicted by the current analysis were attributed to differences with the previously used hydrographs.

An upper limit was placed on breach widths rather than allow the continued slow growth SIMBA predicted. A number of factors led to this decision. First, professional experience indicates that levee breaches rarely exceed the river channel width, which is around 200 feet at flood flow in the Green River. Second, it was considered unrealistic to assume that continued levee breach growth would not be addressed by local jurisdictions with emergency measures once flows dropped to 12,000cfs. At this point, there would be good equipment access to any point along the levee system, and if needed, the Corp of Engineers could possibly reduce the flow further to assist repair efforts. Finally, breach velocities for various design hydrographs (an example is shown in Figure 3-2) consistently dropped below 2 feet/second once the flood peak had passed and flows reduced to 12,000 cfs. Permissible velocities for the typical levee soils found in the Green River are estimated to be in the 2-3 feet/second range (USDA 2007), so continued breach erosion would be unlikely at this point.

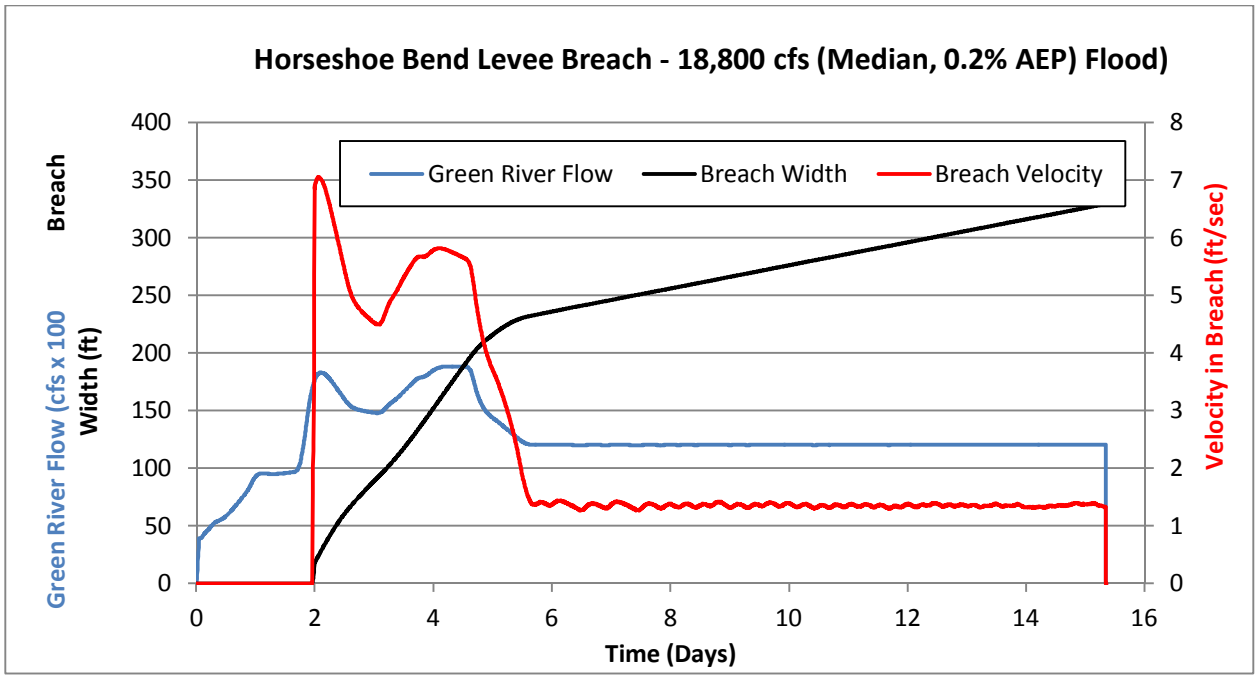


**Figure 3-2 Example SIMBA Breach Growth and Selected Hydraulic Parameters**

Inspection of the simulated breach widths and growth rates showed the variations between sites and design hydrographs were relatively small and unlikely to affect flood inundation results. Therefore, a set of fixed breach parameters was selected based on typical SIMBA results and applied to all levee breach simulations in FLO-2D. The selected breach parameters used a 3 feet/hour vertical erosion rate and 9 feet/hour of horizontal breach growth along the length of the levee, the same magnitudes as were used in the 180$^{th}$ to 200$^{th}$ St study (Tetra Tech 2011). Maximum breach width was capped at 225 feet. Breaches were implemented in the model by initiating levee failure when the water surface elevation in the river reached the trigger elevation. Breach trigger elevations were set to 1-foot above the landward levee toe elevation. This elevation was determined from examination of the levee fragility curves in the accompanying geotechnical memorandum.

Actual breach events may allow more flow on the floodplain than modeled with the simulated breaches for several reasons. Both the SIMBA and FLO-2D models assume that levee breaches do not extend below the floodplain surface. Variations in floodplain and levee elevations at each location therefore resulted in breaches that are of identical final width, but vary in depth and net area. As a result, total flow through the various breaches, which is a function of both available flow area and head through the breach, should not be assumed to be equal. Members of the project team have observed that actual levee breaches often erode well below the floodplain surface, so the simulated breaches may allow less flow through than what would happen in an actual event. It should also be noted that breach growth rates in SIMBA depend in large part on the erodibility parameter, for which there is high uncertainty. Regardless, considering the uncertainty of breach dynamics and levee construction, FLO-2D model results are believed to adequately estimate the overall magnitude of breach flow.

Finally, no sensitivity testing of FLO-2D inundation results compared to breach trigger elevations was performed. It was judged that a rapidly rising hydrograph combined with the large overall flood volumes would result in very little difference in total breach flow – the difference in time of breach at different trigger elevations would vary by only a few hours, whereas total flow durations range from 3 to 15 days.

## 3.6. Existing Conditions Model Simulations

### 3.6.1. HEC-RAS Runs

The full HEC-RAS model was run at 3,500 cfs (Median, 91% AEP) to provide a bounding value for the index location tables of all scenarios, but was not used otherwise.

The clipped HEC-RAS model was used to calculate inundation grids for the Duwamish damage area. Inflows to this model were taken as the outflows from the downstream boundary of the FLO-2D model. Inspection of the outflow hydrographs for the FLO-2D runs (Figure 3-3) revealed that for five of the six flood events, the magnitude of the FLO-2D outflow hydrograph was essentially the same regardless of breach scenario, though the timing varied somewhat. This is attributed to the smaller floods remaining primarily in-channel, and largest floods (the 18,800 and 26,800 cfs events) being of such high volume that flow through the breaches is relatively small compared to the total flow overtopping onto the floodplain. For these five flood events, the overtopping-no-breach simulation outflow hydrograph was used to represent all scenarios.

The 15,100 cfs (High C.L., 1% AEP) flood event was the one event where peak flows differed enough to warrant separate scenario runs. For this event the Dykstra/Tukwila breach scenario and the overtopping-no-breach scenario were similar and therefore combined, while the Horseshoe Bend and Meyers Golf Course Levee breach scenarios were simulated separately. Table 3-3 shows the clipped HEC-RAS simulations completed based on the grouping of FLO-2D outflow hydrographs.

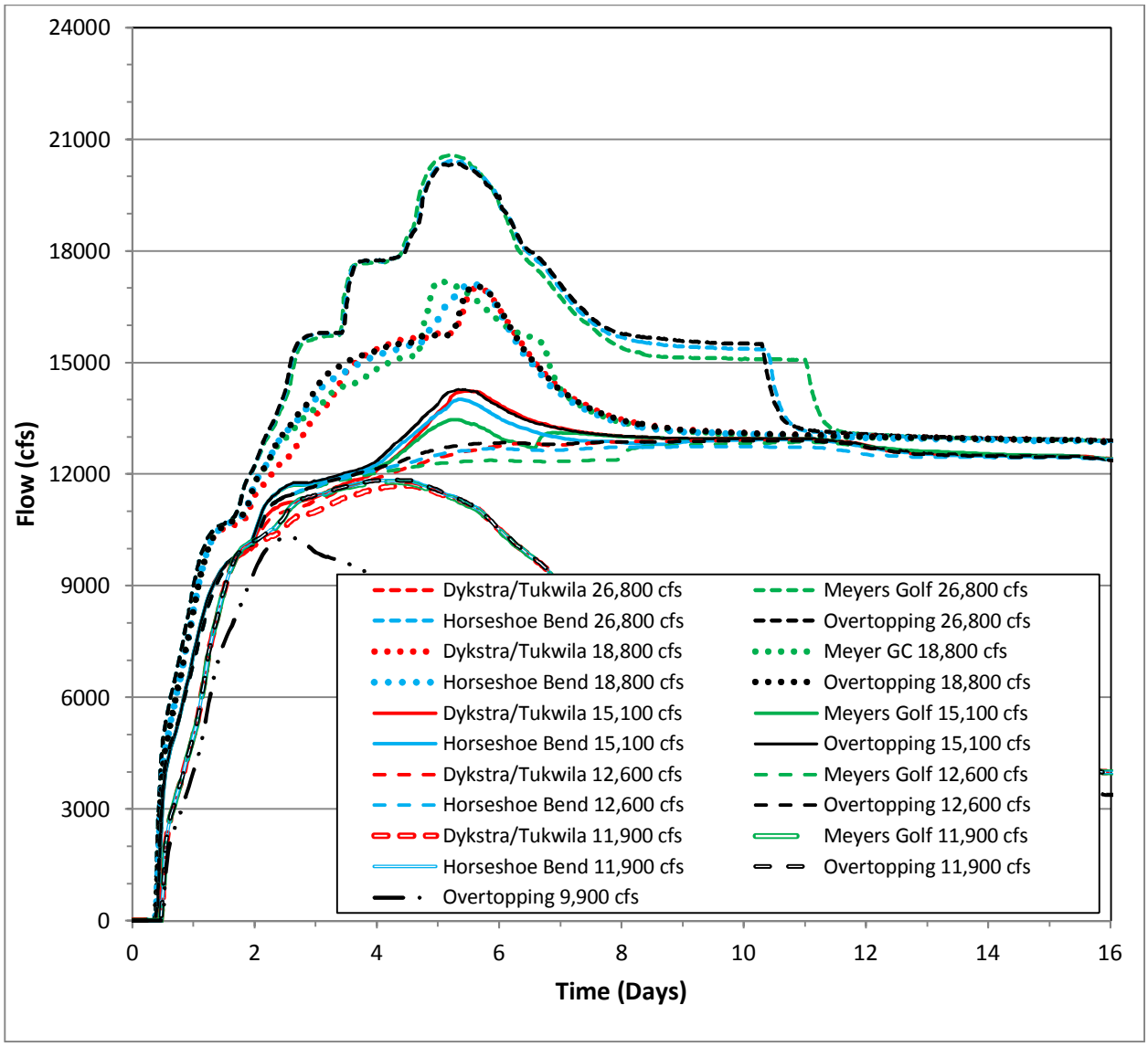


**Figure 3-3 FLO-2D Outflow Hydrographs**

**Table 3-3: Clipped HEC-RAS Model Scenario Runs and Application**

| Flood Event | Peak Flow at Auburn Gage (cfs) | Selected FLO-2D Outflow used in HEC-RAS Run | Scenario Validity for Duwamish Damage Area |
|---|---|---|---|
| Median, 91% AEP | 3,500 | N/A | N/A |
| High C.L., 50% AEP | 9,900 | Overtopping | All Scenarios |
| Low C.L., 10% AEP | 11,900 | Overtopping | All Scenarios |
| Median, 0.5% AEP | 12,600 | Overtopping | All Scenarios |
| High C.L., 1% AEP | 15,100 | Overtopping | Dykstra/Tukwila 205 and Overtopping |
| | | Horseshoe Bend | Horseshoe Bend |
| | | Meyers Golf Course | Meyers Golf Course |
| Median, 0.2% AEP | 18,800 | Overtopping | All Scenarios |
| High C.L., 0.2% AEP | 26,800 | Overtopping | All Scenarios |

### 3.6.2. FLO-2D Runs

The suite of existing condition model runs consisted of three scenarios in which a breach is triggered at a pre-determined location and allowed to grow according to the parameters discussed in Section 3.5. Another set of runs, termed the overtopping-no-breach runs, simulated floods with no breaches; although overtopping was allowed when water levels exceeded levee crest elevations. It is important to note that the overtopping-no-breach simulations were not directly used in the economic analysis for floodplain depth mapping. Composite datasets were developed by post-processing simulation results, as explained in Section 3.7.2.2, and form the fourth scenario, called the levee-overtopping-then-breach scenario.

Each breach scenario consisted of one or two levee breach(es) at the selected location(s). These scenarios were triggered when river levels reached a point one foot above the landward levee toe. The full suite of selected design flood hydrographs (Table 2-2) was run for each scenario. In smaller floods a breach often failed to occur because the channel water surface elevation did not reach the trigger point. In these cases, the results are identical to the overtopping-no-breach simulations, but the runs still form part of the breach scenario.

## 3.7. Development of Hydraulic-economic Inputs

Development of flood depth inundation grids and stage-discharge curves with uncertainty were required for input into the economic damage model. Most information was developed directly from hydraulic model outputs; some was developed using post-processed model results.

### 3.7.1. Stage-Discharge Curve at Index Locations

Stage-discharge curves were developed at index locations for each breach location and damage area evaluated. Index locations were sited a short distance upstream of the selected breach location for each scenario. The discharge for each curve was taken from the Auburn gage and stage at the index location.

**Table 3-4: Index Location Data**

| | Breach | Dykstra | Horseshoe Bend | Meyers Golf | Tukwila | Duwamish |
|---|---|---|---|---|---|---|
| | **River Mile** | **30.80** | **25.55** | **21.83** | **14.93** | **10.68** |
| **Flood Event** | **Flow at Auburn (cfs)** | **Stage (ft)** | | | | |
| Median, 91% AEP | 3,500 | 58.67 | 37.45 | 29.26 | 19.78 | 12.88 |
| High C.L., 50% AEP | 9,900 | 64.15 | 47.13 | 39.03 | 28.7 | 20.62 |
| Low C.L., 10% AEP | 11,900 | 65.51 | 50.04 | 41.56 | 30.57 | 21.75 |
| Median, 0.5% AEP | 12,600 | 65.9 | 51.07 | 43.22 | 31.68 | 22.5 |
| High C.L., 1% AEP | 15,100 | 67.3 | 52.42 | 44.49 | 32.98 | 23.43 |
| Median, 0.2% AEP | 18,800 | 69.01 | 53.6 | 45.85 | 33.95 | 24.98 |
| High C.L., 0.2% AEP | 26,800 | 71.07 | 54.56 | 46.67 | 34.43 | 26.27 |

#### 3.7.1.1. Stage-Discharge Uncertainty

Stage uncertainty for each stage-discharge curve was calculated using the methods for gaged streams described in EM 1110-2-1619 (Corps of Engineers 1996). The standard deviation of error at the Auburn gage from water year 1962 to 2007 was calculated to be 0.32 feet by the Corps of Engineers (2007). A

standard deviation of error in computed water surface of 0.7 feet ("Fair") was selected from Table 5.2 of EM 1110-2-1619 (Corps of Engineers 1996). The total standard deviation used was then calculated as the square root of the sum of the squared standard deviations, or 0.77 feet.

### 3.7.2. Depth Grid Development

The FLO-2D model produces maximum flood depth grids throughout the floodplain for each simulation in a GIS compatible format. Most scenarios used these outputs directly for inundation mapping and as inputs to the economic model, but certain events required additional processing prior to being used. These are described in the following sections.

#### 3.7.2.1. Renton Grid Extension

Preliminary runs showed that under the highest flow scenario of 26,800 cfs (High C.L., 0.2% AEP) the model domain was not large enough to capture the entire area inundated in the City of Renton. Inclusion of this 220 acre area within FLO-2D would not change results significantly because the area is in a backwater and has relatively minor storage available. The extensive effort involved in model modification was not warranted to produce results for only one flood. Instead, an extension grid that matched the FLO-2D grid was created to cover this area (Figure 1-1), and water surface elevations manually set within it based on adjoining simulated water surface elevations.

#### 3.7.2.2. Composite Levee-Overtopping-Then-Breach Scenario Grids

The overtopping-no-breach scenario was required for development of index location data and estimation of the existing level of protection. However, it was the consensus of the project team that under real-world conditions the levees were much more likely to breach than to remain intact once overtopped. The overtopping-no-breach simulations did not reflect this condition, and could therefore under-estimate flood depths in the damage areas. The various breach scenario simulations could not be used directly because breaching due to overtopping will tend to occur at low points in the system which does not necessarily correlate with locations identified as having the highest risk of geotechnical failure. In addition, flood depths in a damage area would tend to be lower should an overtopping breach occur elsewhere in the system.

Therefore, a series of composite flood depth inundation grids were used to develop the levee-overtopping-then-breach scenario, reflecting the project team's view that breaches will likely occur when the levee is overtopped. These composite grids replaced the overtopping-no-breach depth grids for those flood events where overtopping occurs into a damage area. The scenario was named the levee-overtopping-then-breach scenario to clarify this approach.

The approach was undertaken using the completed FLO-2D runs. Each composite grid was created by averaging depths from different breach scenarios, equally weighting the probability of each breach in the composite grid. Breach scenario grids were not included where areas did not overtop. The number of composite grids created was limited, as overtopping only occurs in the three largest events. Due to overtopping occurring into some damage areas and not others, each flood event was treated uniquely.

In the 15,100 cfs (High C.L., 1% AEP) event, there is no overtopping into the Auburn or Tukwila damage areas, only the Kent/Renton area. Therefore, only the Meyers Golf Course and Horseshoe Bend breach depth grids were averaged, and the results only applied to the Kent/Renton Damage Area (Figure 3-25).

For the 18,800 cfs (Median, 0.2% AEP) event, overtopping occurred into the Auburn and Kent/Renton Damage Areas, but not the Tukwila area. All three breach scenarios (Dykstra/Tukwila, Horseshoe Bend and Meyers Golf Course) were averaged. Only the Auburn and Kent/Renton damage areas had the

composite grids applied: the Tukwila damage area did not overtop and hence kept its original dry grid (Figure 3-26).

The 26,800 cfs (High C.L., 0.2% AEP) event overtops into all damage areas. Here all three breach scenario grids were averaged and the results applied to the three damage areas (Figure 3-27).

Flood depth results from the composite grid process were generally within a few tenths of a foot of the overtopping-no-breach runs in most locations. Differences were greatest in the Tukwila damage area for the 26,800 cfs (High C.L., 0.2% AEP) run. In this area, the overtopping-no-breach inundation was shallow and limited in area (Figure 3-30), so replacement with breach composite data created much larger flood inundation areas and deeper depths, shown in Figure 3-27. No compositing of grids was performed for the Duwamish damage area as no with-breach hydraulic simulations were performed.

#### 3.7.2.3. Summary of Scenario Depth Grid Packages

Inundation depth grids directly from model output, the Renton area grid extension, and the composite overtopping breach grid process, were assembled and delivered to the economics team for analysis. Each of the four scenarios had depth grids for the six design flood events. The FLO-2D and clipped HEC-RAS model results were delivered separately. In addition, the three largest overtopping-no-breach FLO-2D scenarios, which are not directly used in the economic analysis, were produced. A summary of data sources for each scenario is given in Table 3-5.

**Table 3-5: Depth Grid Sources**

| | Breach Scenario | | | Overtopping Scenario |
|---|---|---|---|---|
| **Flood** | **Dykstra/ Tukwila** | **Horseshoe Bend** | **Meyers Golf Course** | **Levee-Overtopping-Then-Breach** |
| 3,500 cfs (Median, 91% AEP) | A | A | A | A |
| 9,900 cfs (High C.L., 50% AEP) | M | M | M | M |
| 11,900 cfs (Low C.L., 10% AEP) | M | M | M | M |
| 12,600 cfs (Median, 0.5% AEP) | M | M | M | M |
| 15,100 cfs (High C.L., 1% AEP) | M | M | M | C |
| 18,800 cfs (Median, 0.2% AEP) | M | M | M | C |
| 26,800 cfs (High C.L., 0.2% AEP) | M, R | M, R | M, R | C, R |

Codes: A - Corps of Engineers Full River HEC-RAS model
M – Direct model output (Lower River HEC-RAS model for Duwamish damage area, FLO-2D for others)
C – Composite Depth Grid
R – Renton Grid extension data added

## 3.8. Findings

### 3.8.1. Inundation Maps

Depth inundation maps for all 24 scenario-design flood event combinations used for the economic analysis are included as figures following this section. In addition, inundation maps for the three largest overtopping-no-breach runs are included; these runs were not used in the economic analysis, where the composite grids described in 3.7.2.2 replaced them. The separate Existing Conditions Economics

Technical Memorandum describes how these results were used in the economic assessment. Key results for the various damage areas and breach scenarios are as follows:

- Inundation of the Auburn damage area due to the Dykstra Levee breach is shown in Figure 3-4 through Figure 3-9. Minor overtopping of the un-leveed left bank between RM 26 and 28 first occurs in the 9,900 cfs (High C.L., 50% AEP) flood. Also apparent in this event (Figure 3-4) is the backwater flooding of the Mullen Slough area. The first overtopping of the upper Auburn levee system occurs in the 15,100 cfs (High C.L., 1% AEP) flood between RM 29.5 and 30 (Figure 3-7). The Dykstra levee breach is not triggered until the 18,800 cfs (Median, 0.2% AEP) flood (Figure 3-9). Significant overbank flow into urbanized areas is limited above RM 31 under even the largest flow (Figure 3-9).
- The Tukwila Levee breach scenario is also shown on Figure 3-4 through Figure 3-9: The landward levee toe elevation at the breach location is low, so a breach is triggered even in the 9,900 cfs (High C.L., 50% AEP) flood. Floodwaters entering the damage area are confined by the levee system and must exceed the downstream levee crest elevation in order to spill back out into the Green River. The levee elevations provide a control on interior water levels; as a result extents and depths of inundation in the damage area are fairly similar over a wide range of floods. The level of protection the existing levee provides is demonstrated in Figure 3-30, which shows that at the highest flow simulated (26,800 cfs) levee overtopping is limited to the lower end. The shallow depths within the damage area indicate the depth and volume of overtopping are small. For the economic analysis, the composite grid assuming a levee breach would occur with overtopping (Section 3.7.2.2) is used: this results in much deeper and more extensive flooding of the area (Figure 3-27).
- The Horseshoe Bend Levee breach is first triggered at the 11,900 cfs (Low C.L., 10% AEP) flood (Figure 3-11), although inundation extents are small. In larger floods breach flows are initially confined by railroad embankments before spreading out over a wider floodplain extent to the north. In the 18,800 cfs (Median, 0.2% AEP) flood of the Black River Pump Station still has enough capacity to allow collection of flows into lower Springbrook Creek, preventing flooding of the area near to and north of I-405 (Figure 3-14). At 26,800 cfs the pump station is overwhelmed, floodwaters back up towards the Cedar River and spill out back into the Green River over much of the lower levee system (Figure 3-15).
- The Meyers Golf Course Levee breach is also initially triggered at the 11,900 cfs (Low C.L., 10% AEP) flood (Figure 3-17). Overbank flows are northward before passing under the railroad embankments at various openings. At 15,100 cfs (High C.L., 1% AEP), overtopping upstream of the breach into the damage area is beginning to occur (Figure 3-19). The Black River Pump Station is able to keep up with flows through the 18,800 cfs (Median, 0.2% AEP) flood (Figure 3-20).
- The Duwamish damage area did not have levee breach scenarios applied, in part because most of the facilities in the Duwamish area are revetments, not levees. Overbank flooding is limited to areas above RM 8, indicating levees and natural banks downstream do not overtop in any size event simulated.

### 3.8.2. Channel Conveyance Capacity

The limited number of simulations completed and the role of flood volume as well as peak flow in determining maximum flood levels means that conveyance capacity of the levee system can only be approximately estimated. As mentioned previously, there is over a one foot difference in maximum channel water surface elevations between the 11,900 and 12,600 cfs floods: this is attributed to flood

volume differences, not the relatively small change in peak flow. The existing conveyance capacity, especially for downstream reaches, relies on overtopping in many locations throughout the system. Because raising a levee in one area can increase water levels elsewhere, hydraulic modeling will be required to evaluate overall changes to the system conveyance capacity.

- The Auburn damage area benefits in the upper end from the channel being naturally confined within the Auburn narrows. Upstream levees on the left bank (RM 28 to RM 31.75) convey flows between the 15,100 cfs (High C.L. 1% AEP) and the 18,800 cfs (Median, 0.2% AEP) floods. The lowest capacity in this reach is around RM 29.8, with overtopping occurring around the 15,100 cfs (High C.L. 1% AEP) flood. The newly constructed Reddington setback levee (RM 28.25 to RM 29.5) contains the 18,800 cfs (Median, 0.2% AEP) flood with some freeboard, and is estimated to have a 70%-90% probability of containing the 26,800 cfs (High C.L., 0.2% AEP) flood (NHC 2013).
- The Kent/Renton damage areas, protected by PL 84-99 right bank levees, generally has lower capacity in the upper areas, with low areas in the Horseshoe Bend levee (RM 24-26) and the levees around SR516 (RM 22). The minimum capacity at Horseshoe Bend is approximately at the 12,600 cfs (Median, 0.5% AEP) flood. As this is very close to the 12,000 cfs regulation target, overtopping risk is high during a large volume flood that may not necessarily exceed regulation ability at HHD. This occurs over a fairly short reach of the levee. The minimum capacity averaged over the levee system is between the 15,100 cfs (High C.L., 1% AEP) and the 18,800 cfs (Median, 0.2% AEP) floods.
- The Tukwila damage area is protected by the Tukwila 205 levee that provides a high level of overtopping protection. Overtopping only occurs in the lower end of this levee (RM 12.5) and only in the 26,800 cfs (High C.L., 0.2% AEP) flood. The Segale South Tukwila project is rebuilding the levee upstream to the same high level of protection, and no overtopping under any design hydrograph occurs.
- The Duwamish damage area begins to see overbank inundation in the 12,600 cfs flood (Median, 0.5% AEP), and above RM 8 is fully inundated in the 18,800 cfs flood (Median, 0.2% AEP). Below RM8 the channel conveyance expands due to tidal influence and dredging and there no overbank flooding in any event simulated.

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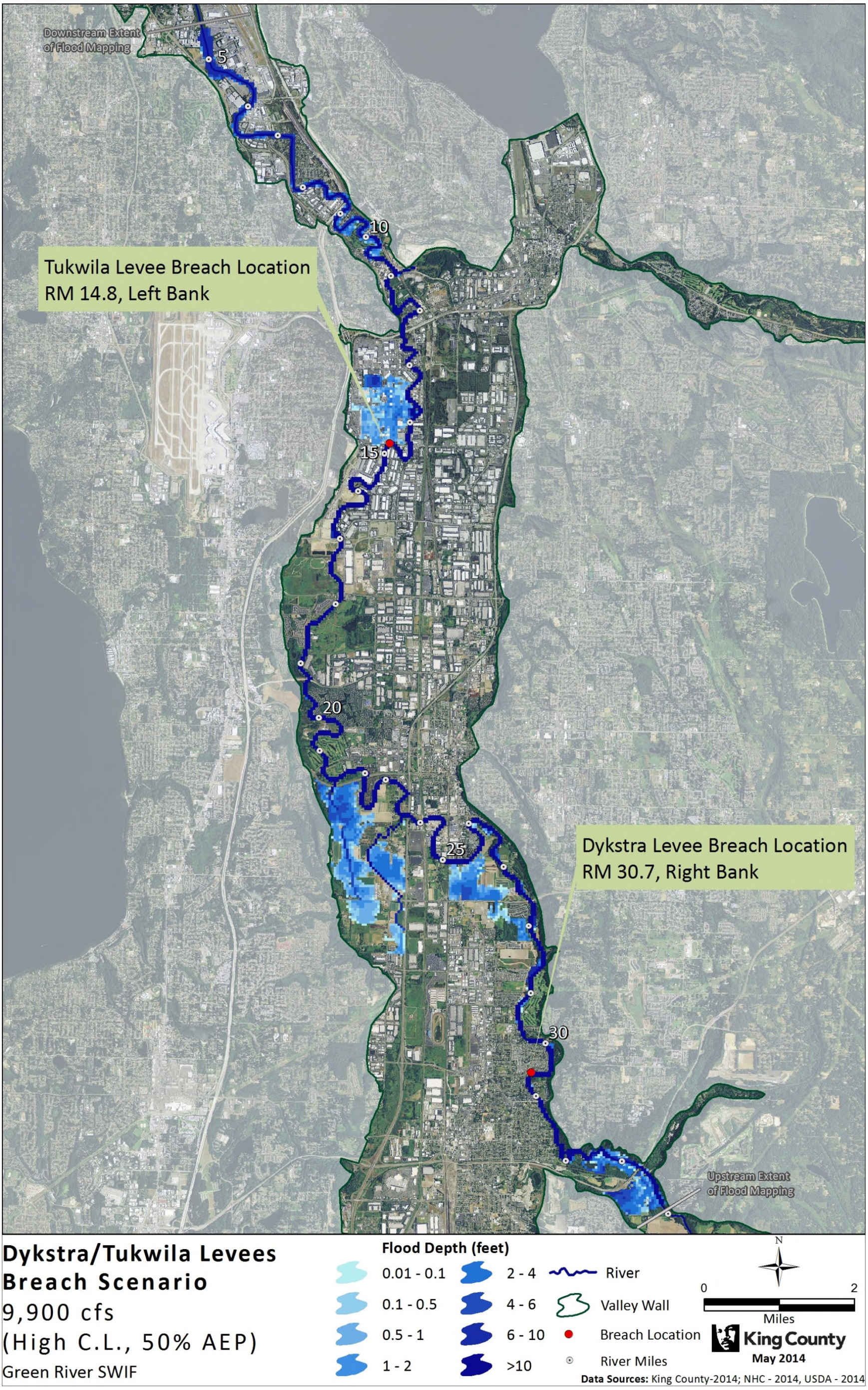


Figure 3-4 Inundation Map - Dykstra/Tukwila Levees Breach Scenario-9,900 cfs (High C.L., 50% AEP)

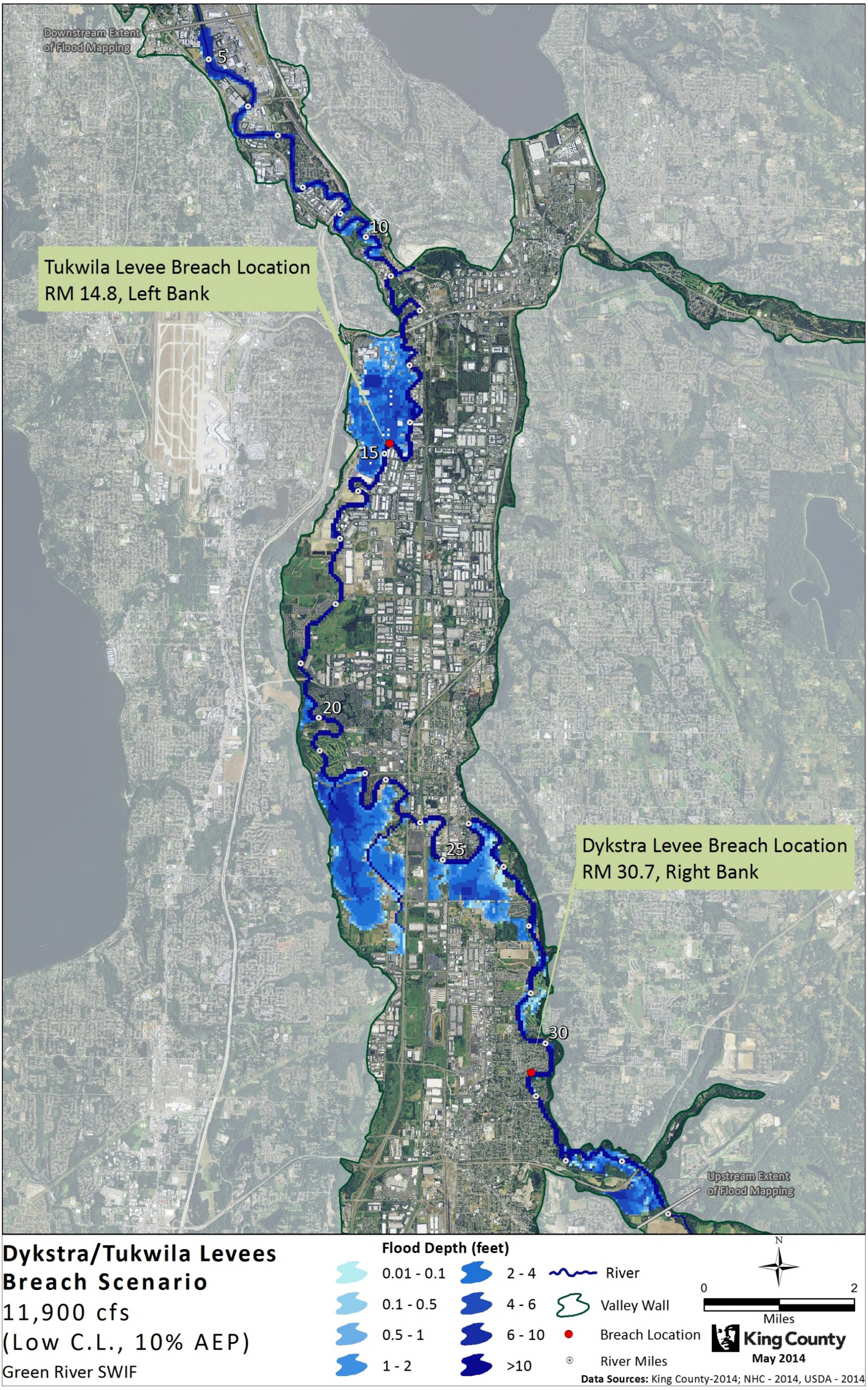


Figure 3-5 Inundation Map - Dykstra/Tukwila Levees Breach Scenario-11,900 cfs (Low C.L., 10% AEP)

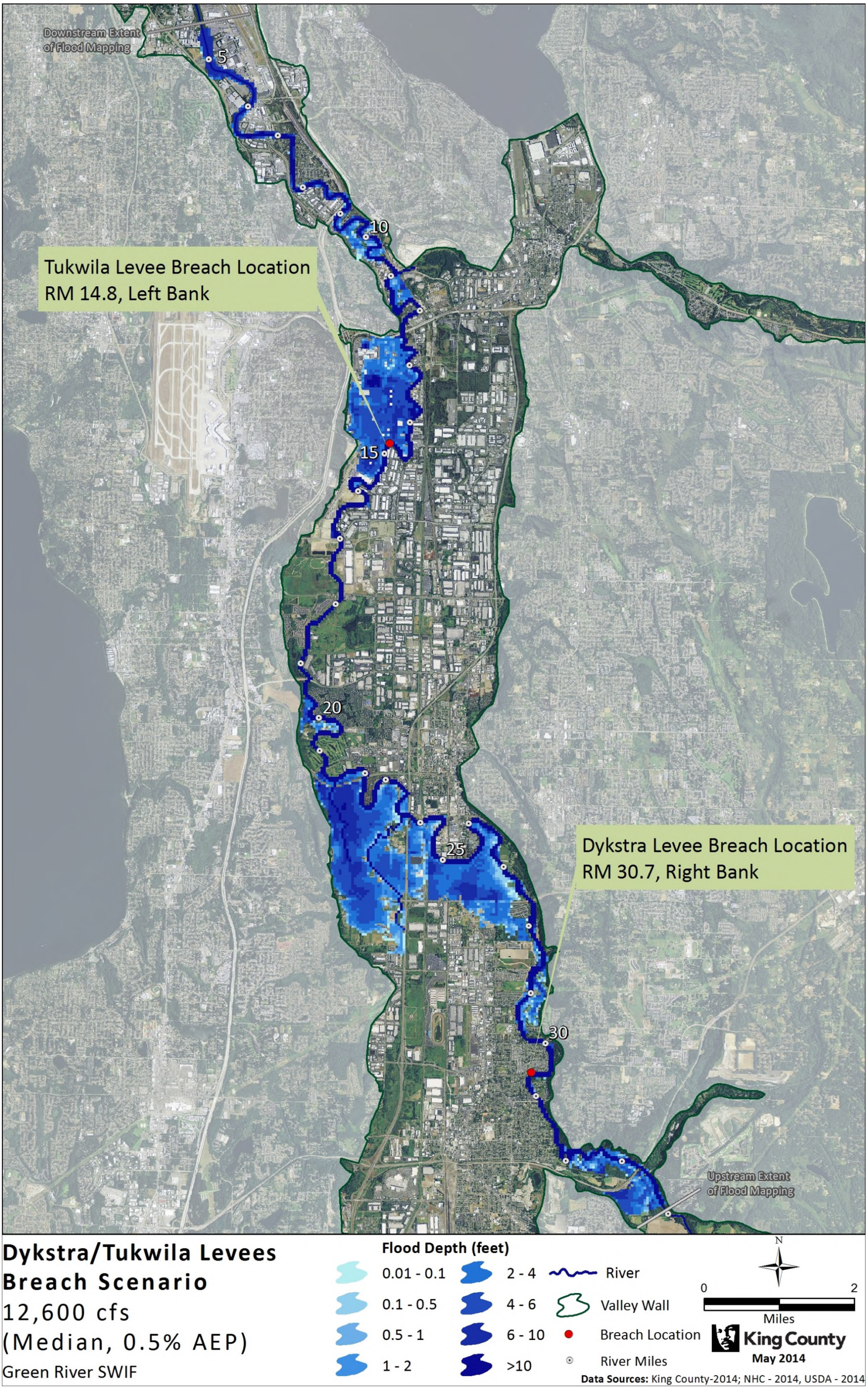


Figure 3-6 Inundation Map - Dykstra/Tukwila Levees Breach Scenario- 12,600 cfs (Median, 0.5% AEP)

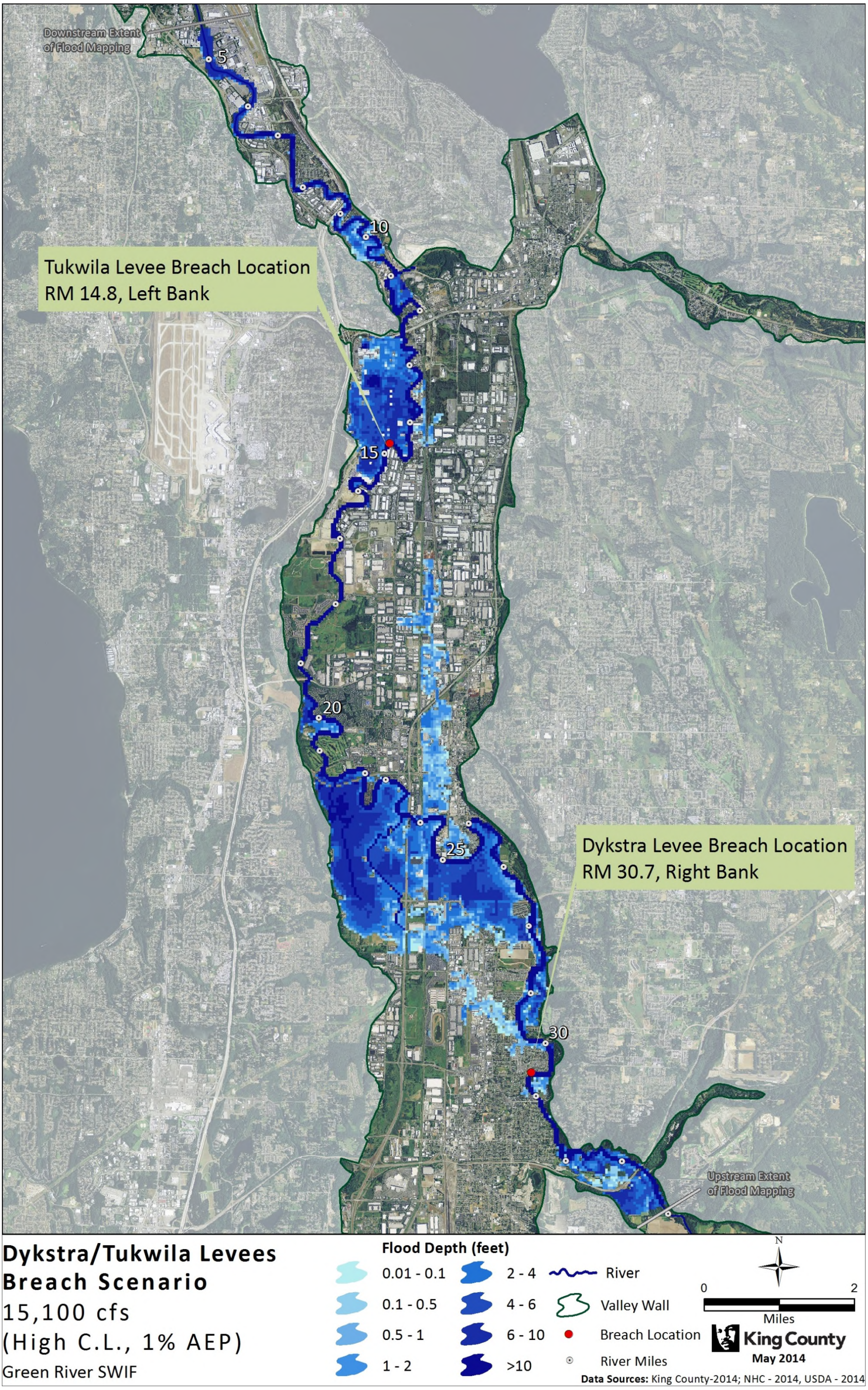


Figure 3-7 Inundation Map - Dykstra/Tukwila Levees Breach Scenario-15,100 cfs (High C.L., 1% AEP)

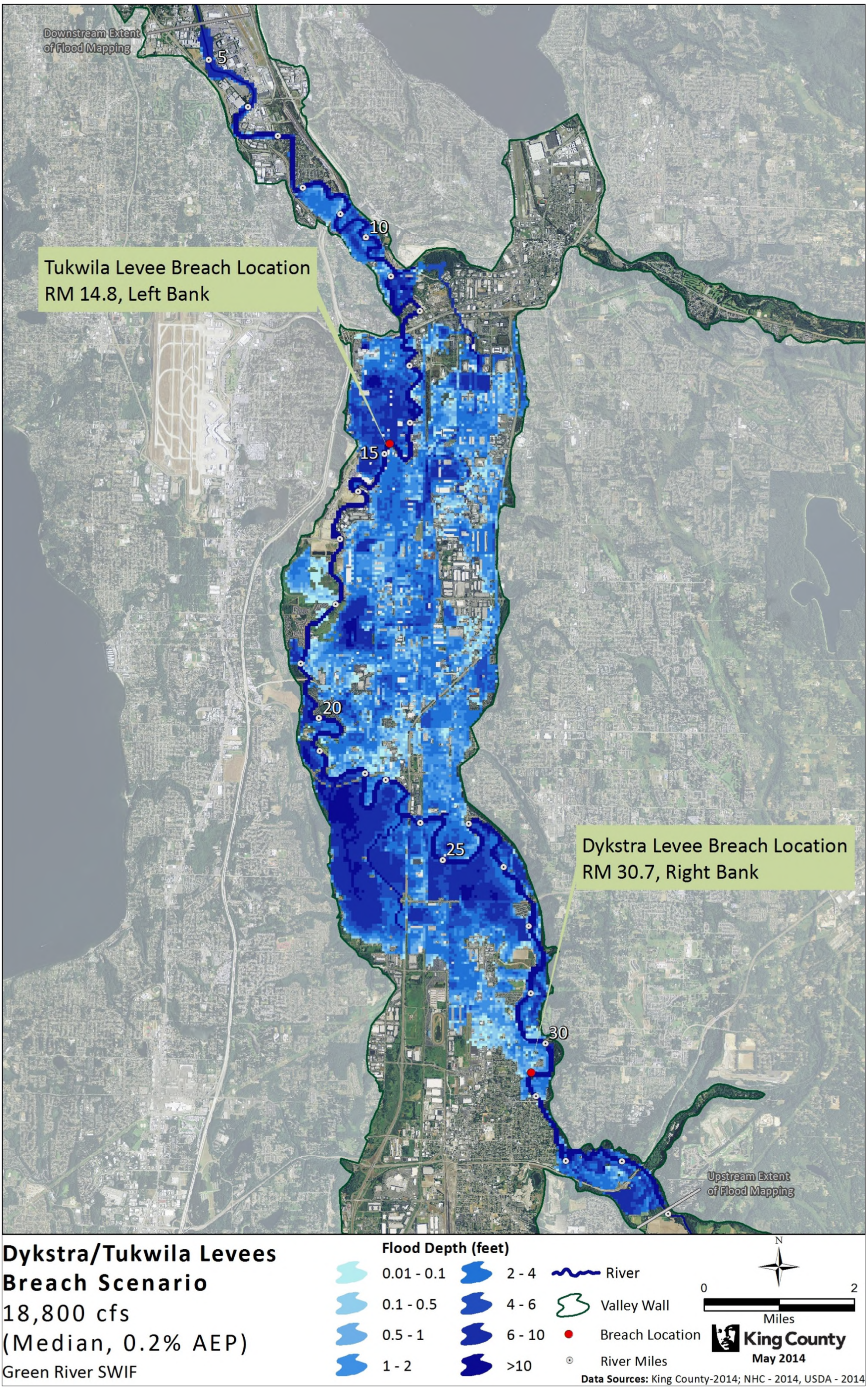


Figure 3-8 Inundation Map - Dykstra/Tukwila Levees Breach Scenario-18,800 cfs (Median, 0.2% AEP)

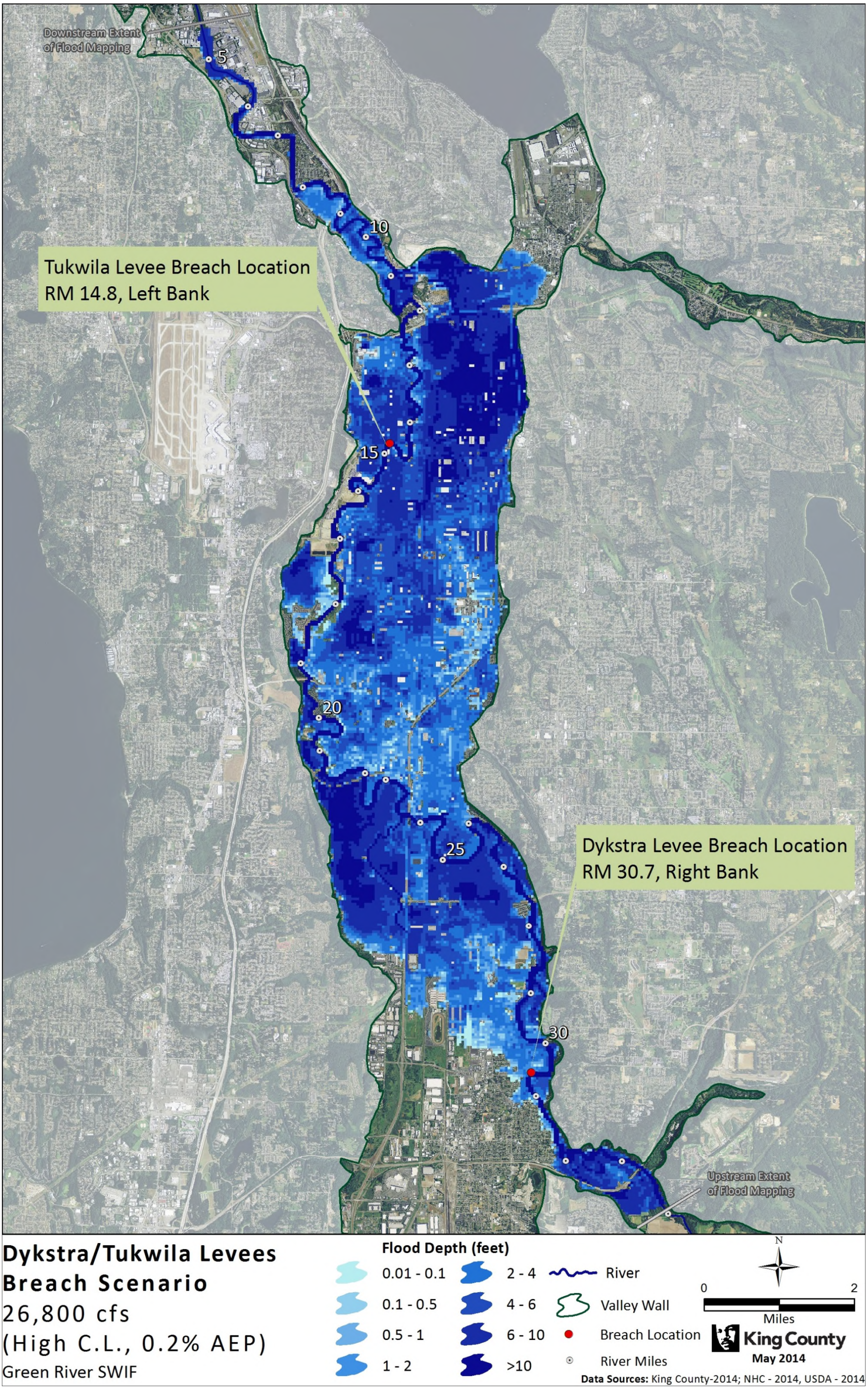


Figure 3-9 Inundation Map - Dykstra/Tukwila Levees Breach Scenario-26,800 cfs (High C.L., 0.2% AEP)

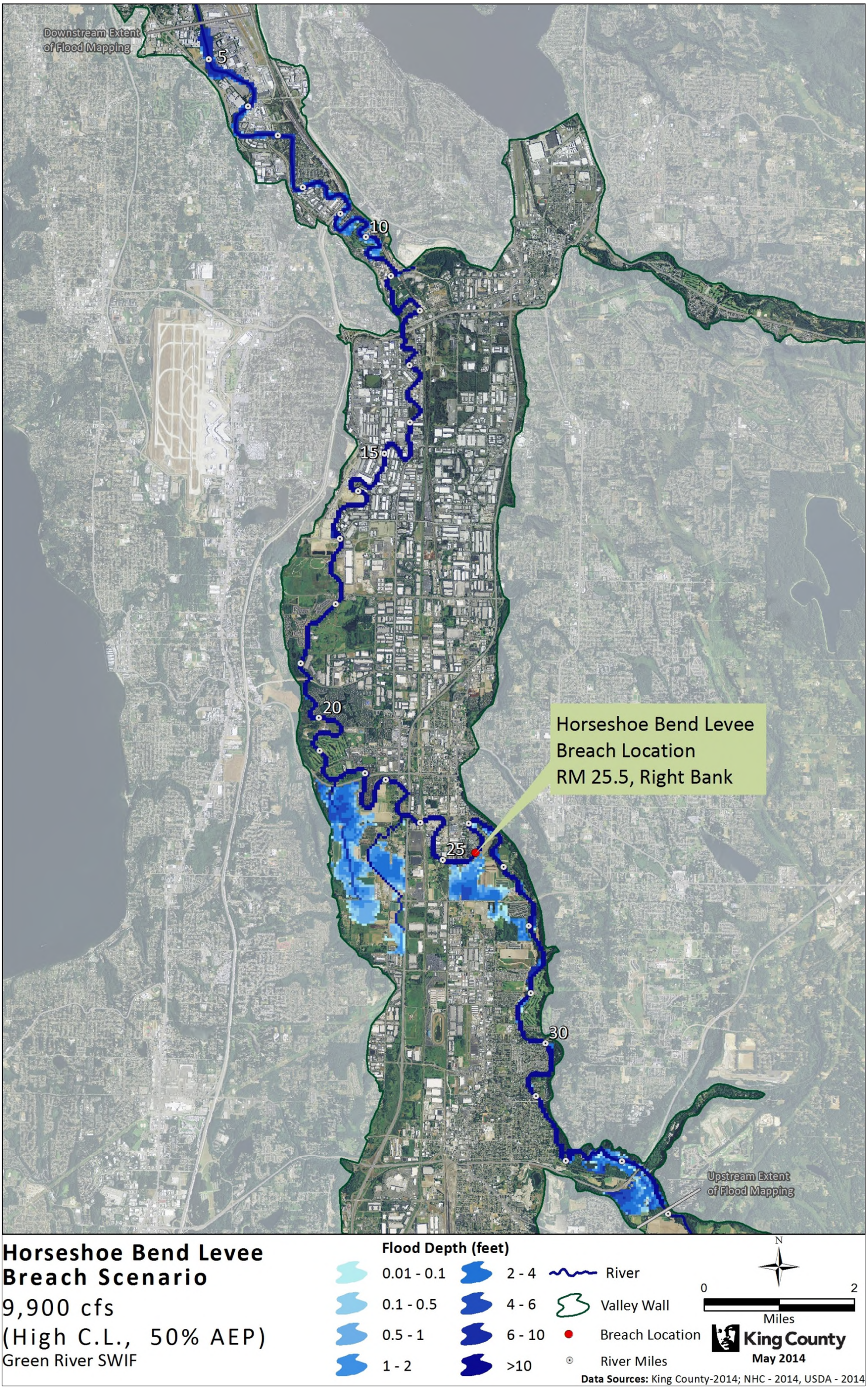


Figure 3-10 Inundation Map – Horseshoe Bend Levee Breach Scenario-9,900 cfs (High C.L., 50% AEP)

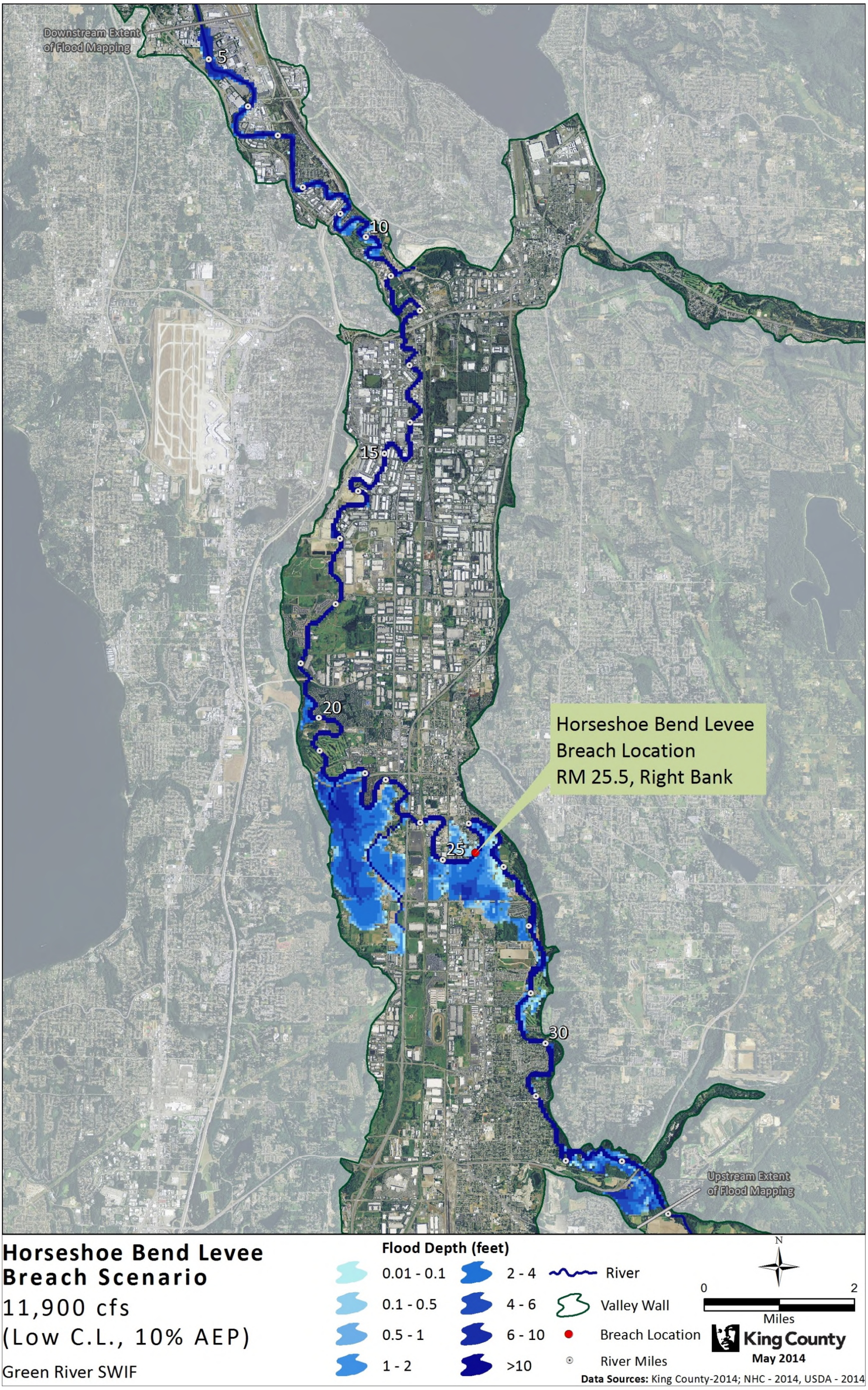


Figure 3-11 Inundation Map – Horseshoe Bend Levee Breach Scenario-11,900 cfs (Low C.L., 10% AEP)

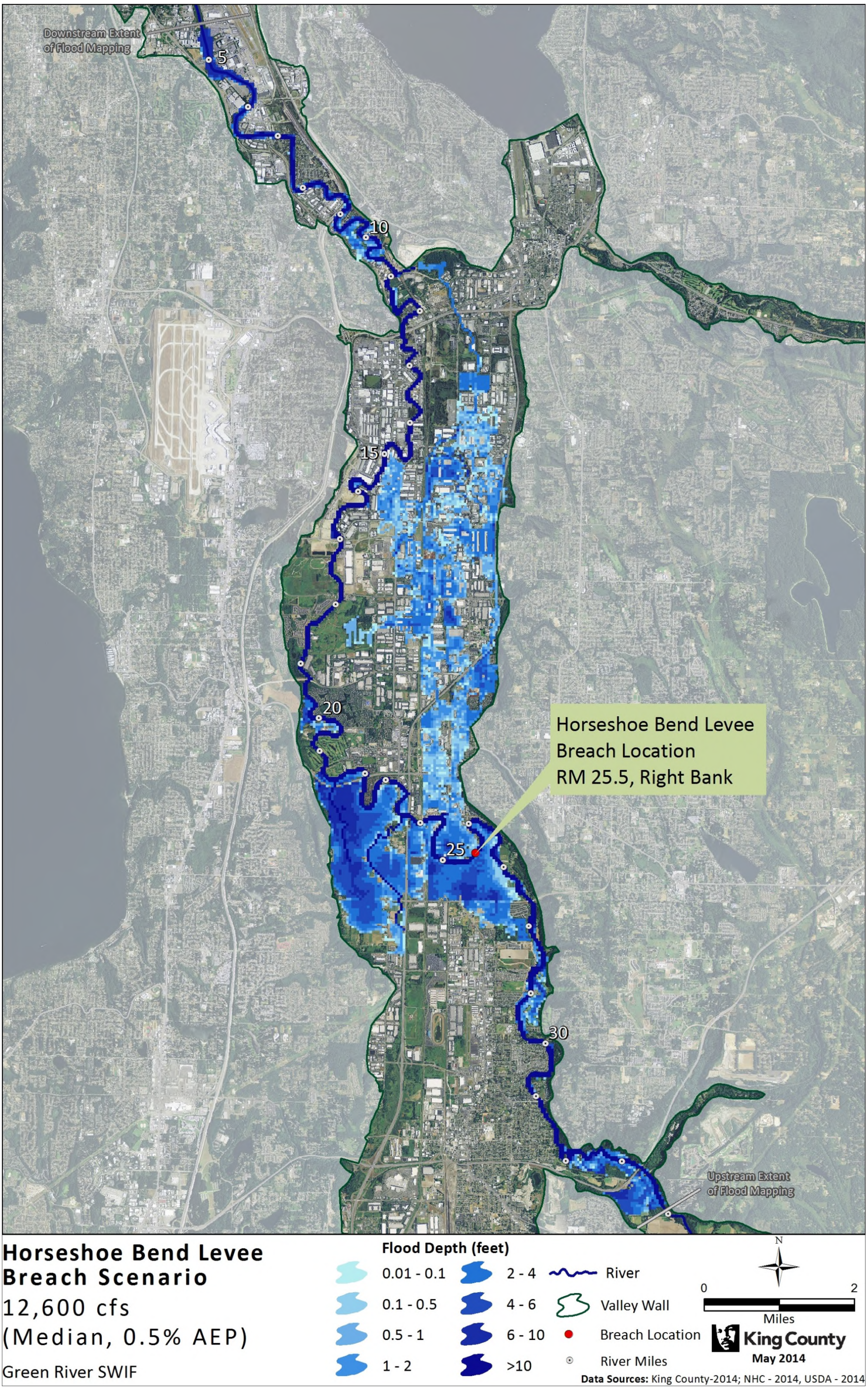


Figure 3-12 Inundation Map – Horseshoe Bend Levee Breach Scenario-12,600 cfs (Median, 0.5% AEP)

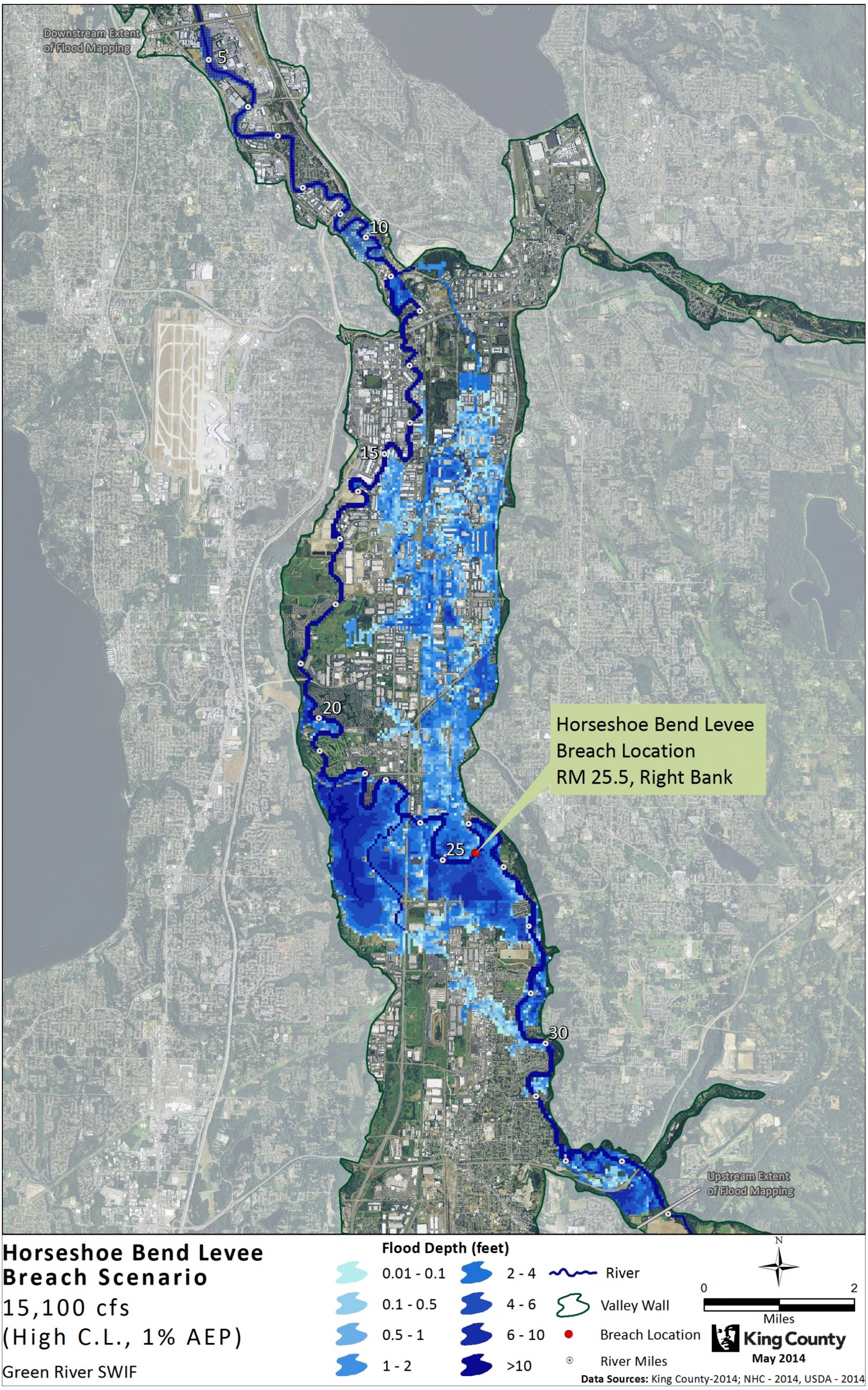


Figure 3-13 Inundation Map – Horseshoe Bend Levee Breach Scenario-15,100 cfs (High C.L., 1% AEP)

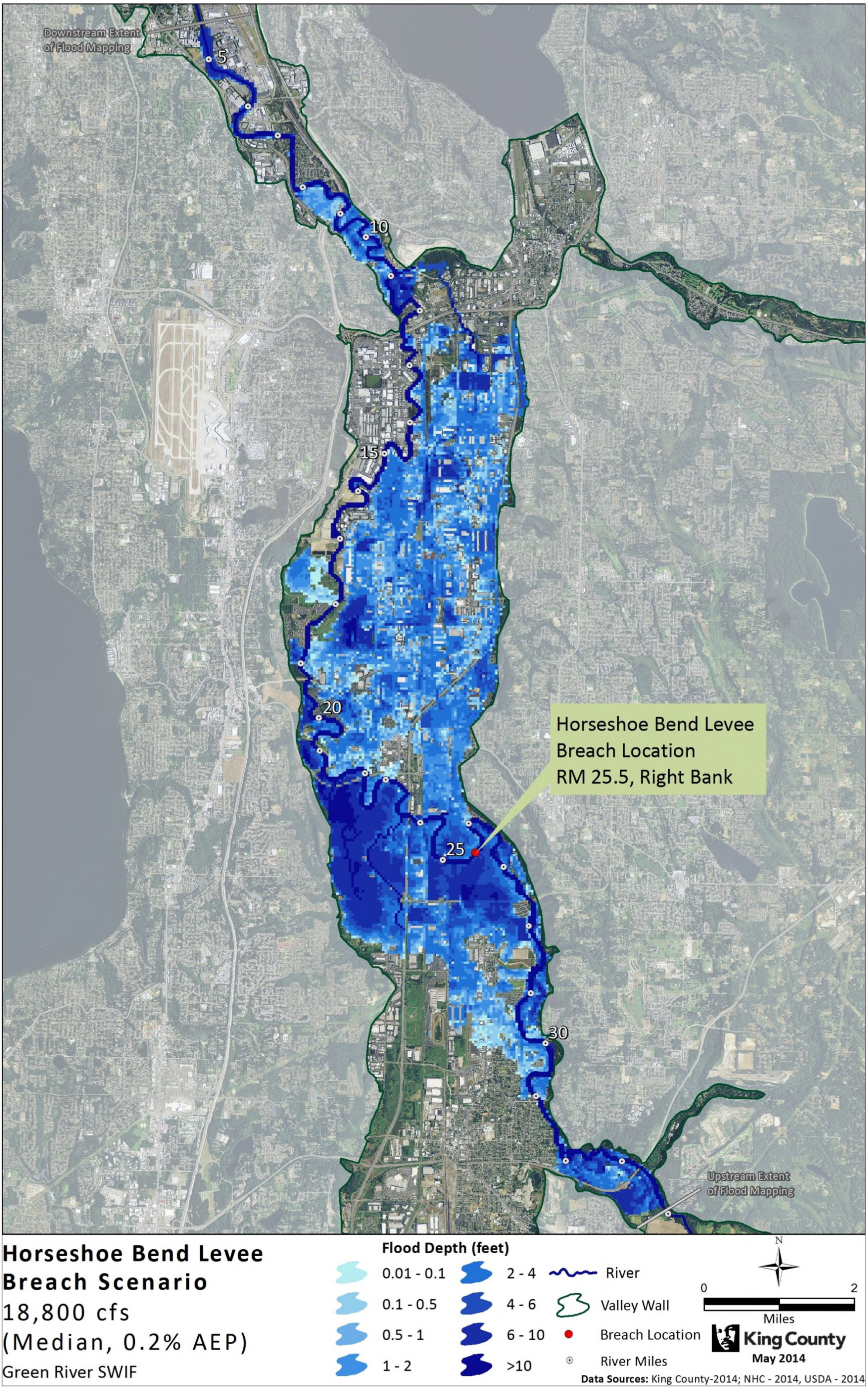


Figure 3-14 Inundation Map – Horseshoe Bend Levee Breach Scenario-18,800 cfs (Median, 0.2% AEP)

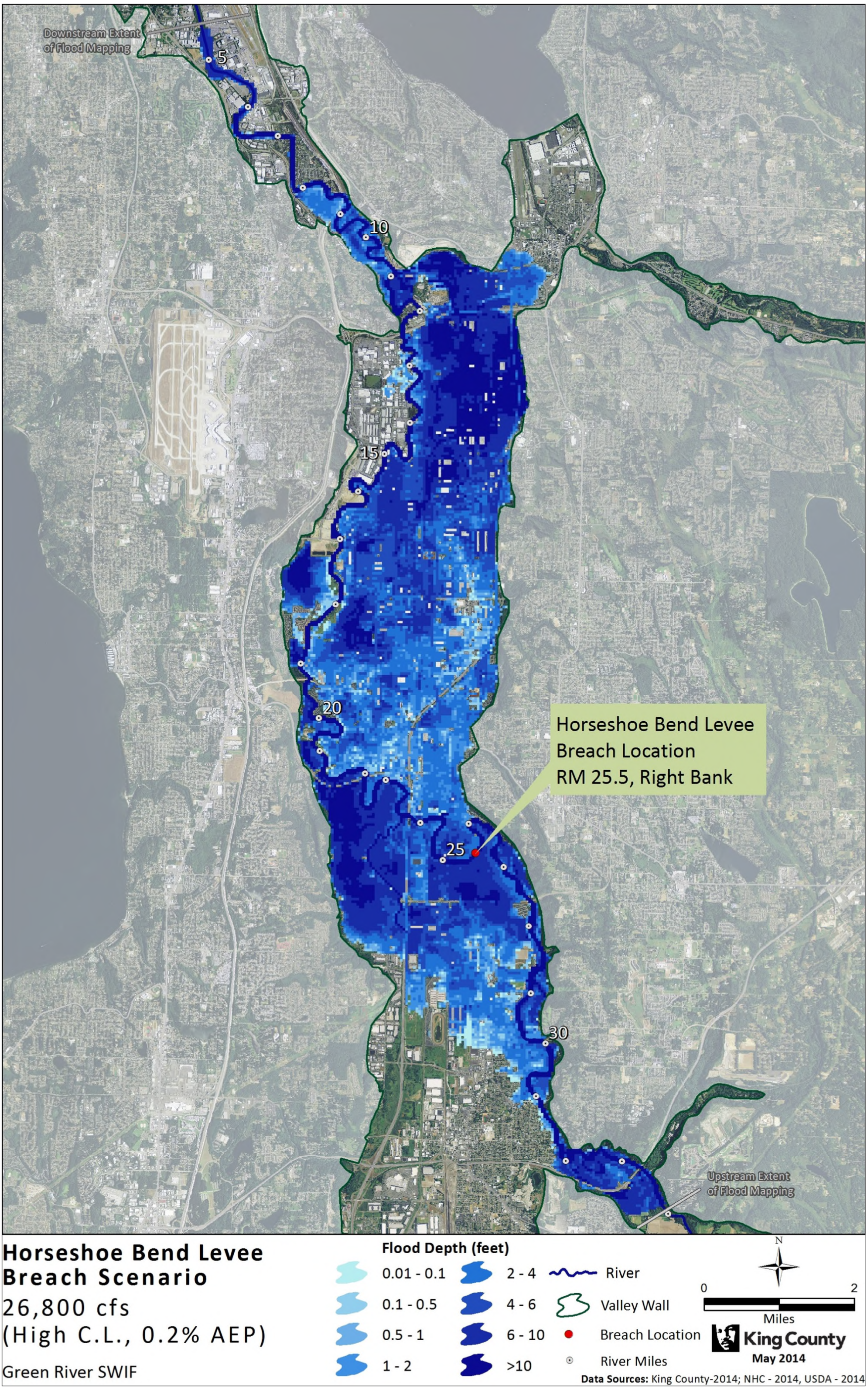


Figure 3-15 Inundation Map – Horseshoe Bend Levee Breach Scenario-26,800 cfs (High C.L., 0.2% AEP)

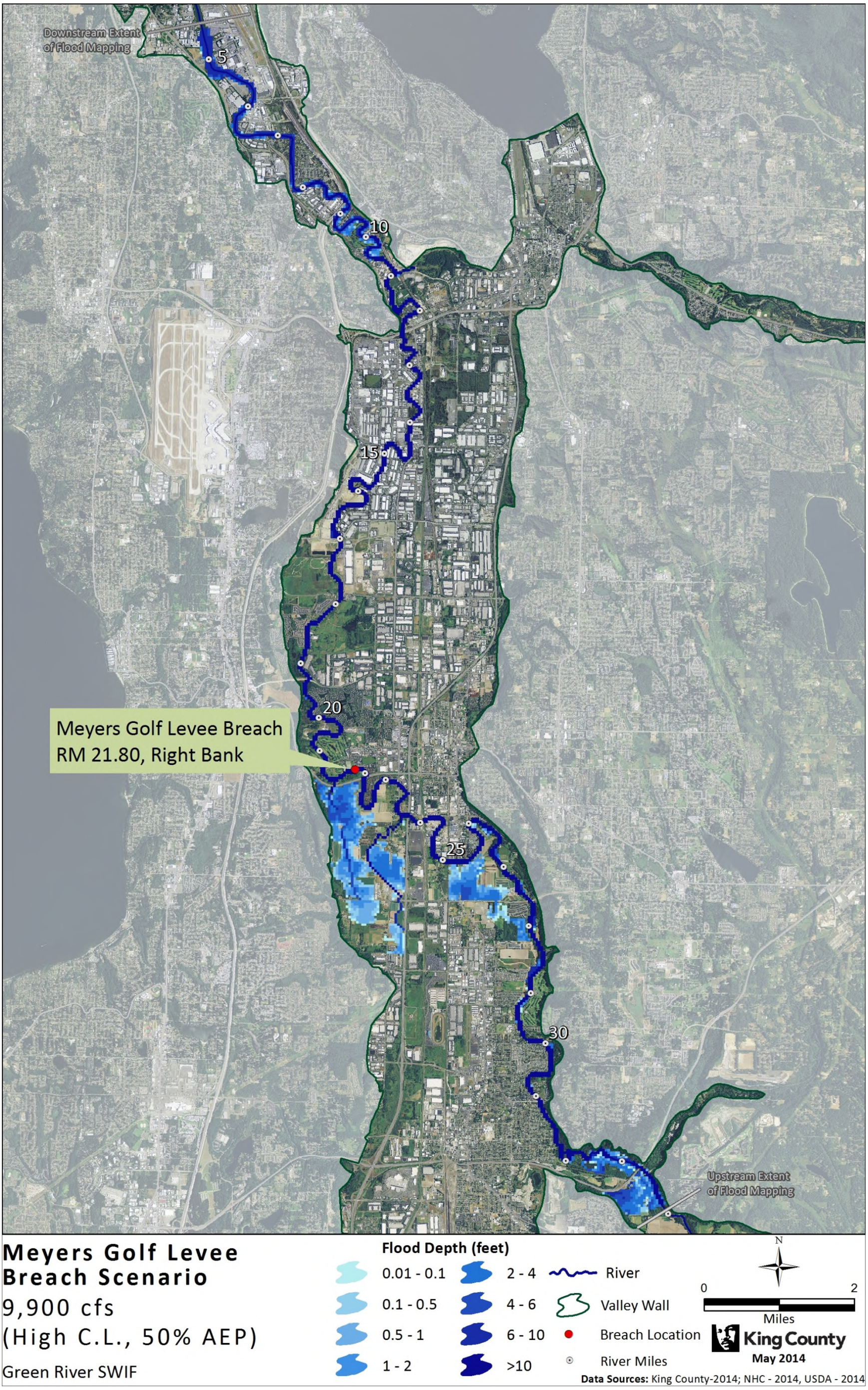


Figure 3-16 Inundation Map – Meyers Golf Course Levee Breach Scenario-9,900 cfs (High C.L., 50% AEP)

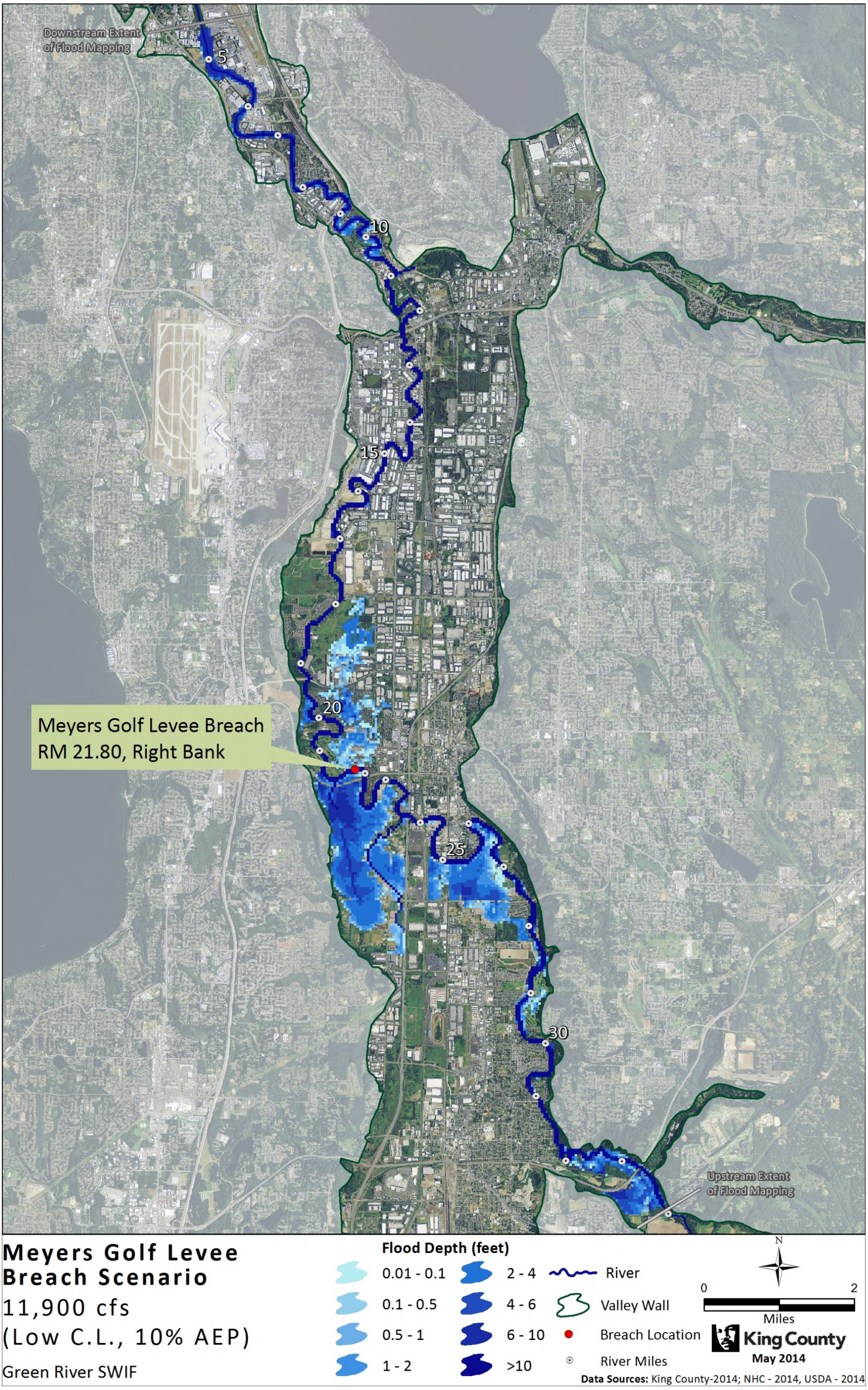


Figure 3-17 Inundation Map – Meyers Golf Course Levee Breach Scenario-11,900 cfs (Low C.L., 10% AEP)

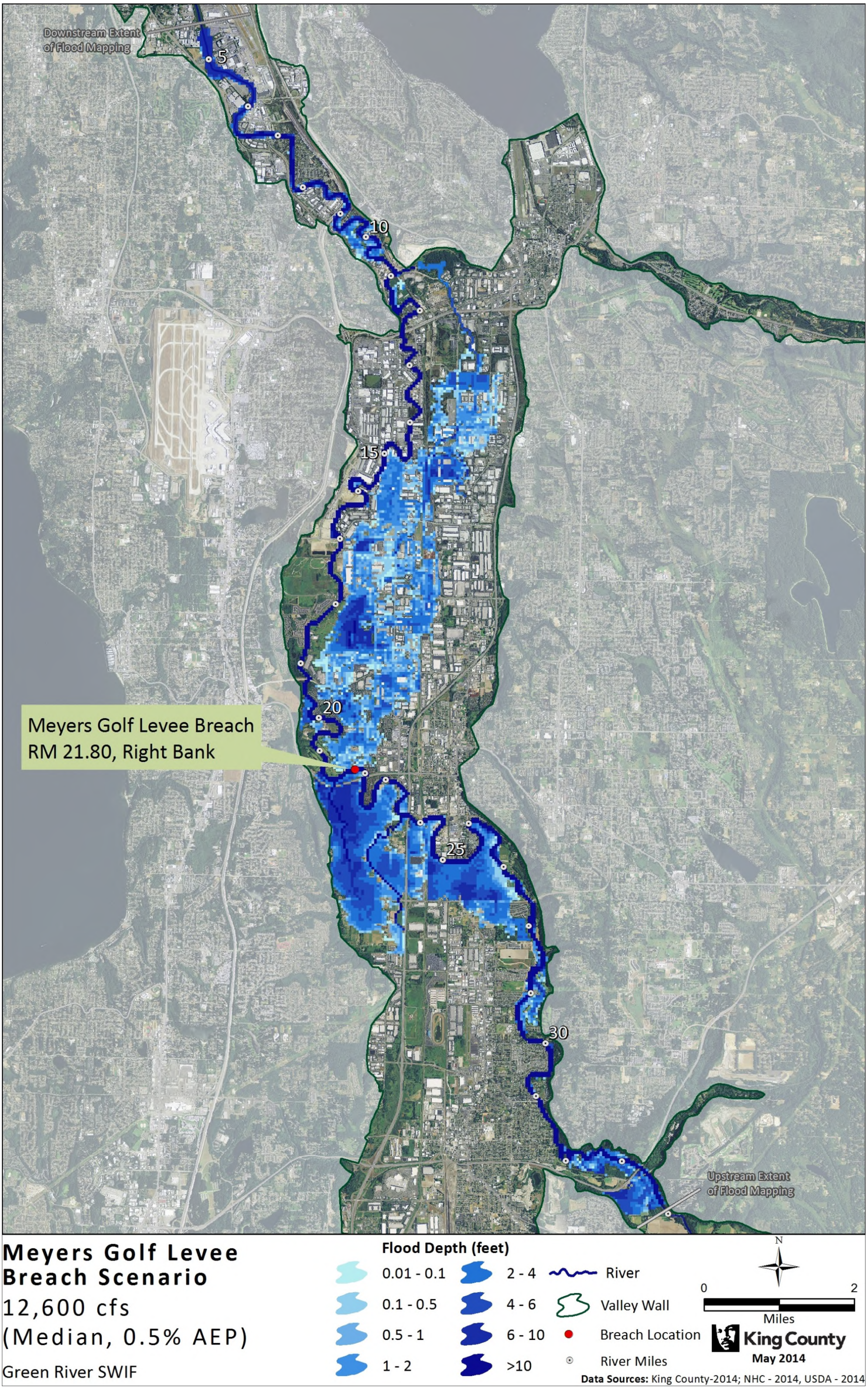


Figure 3-18 Inundation Map – Meyers Golf Course Levee Breach Scenario-12,600 cfs(Median, 0.5% AEP)

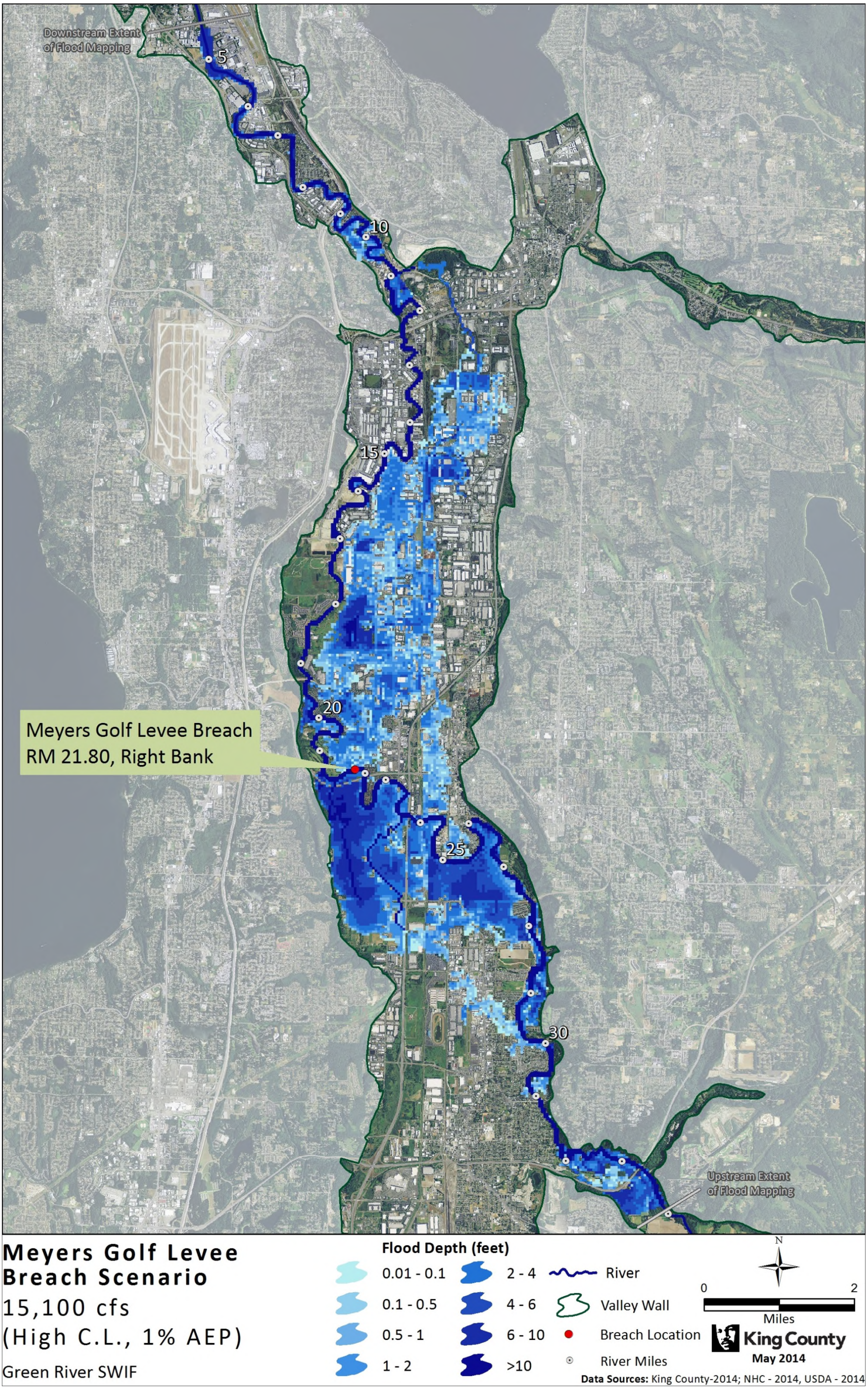


Figure 3-19 Inundation Map – Meyers Golf Course Levee Breach Scenario-15,100 cfs (High C.L., 1% AEP)

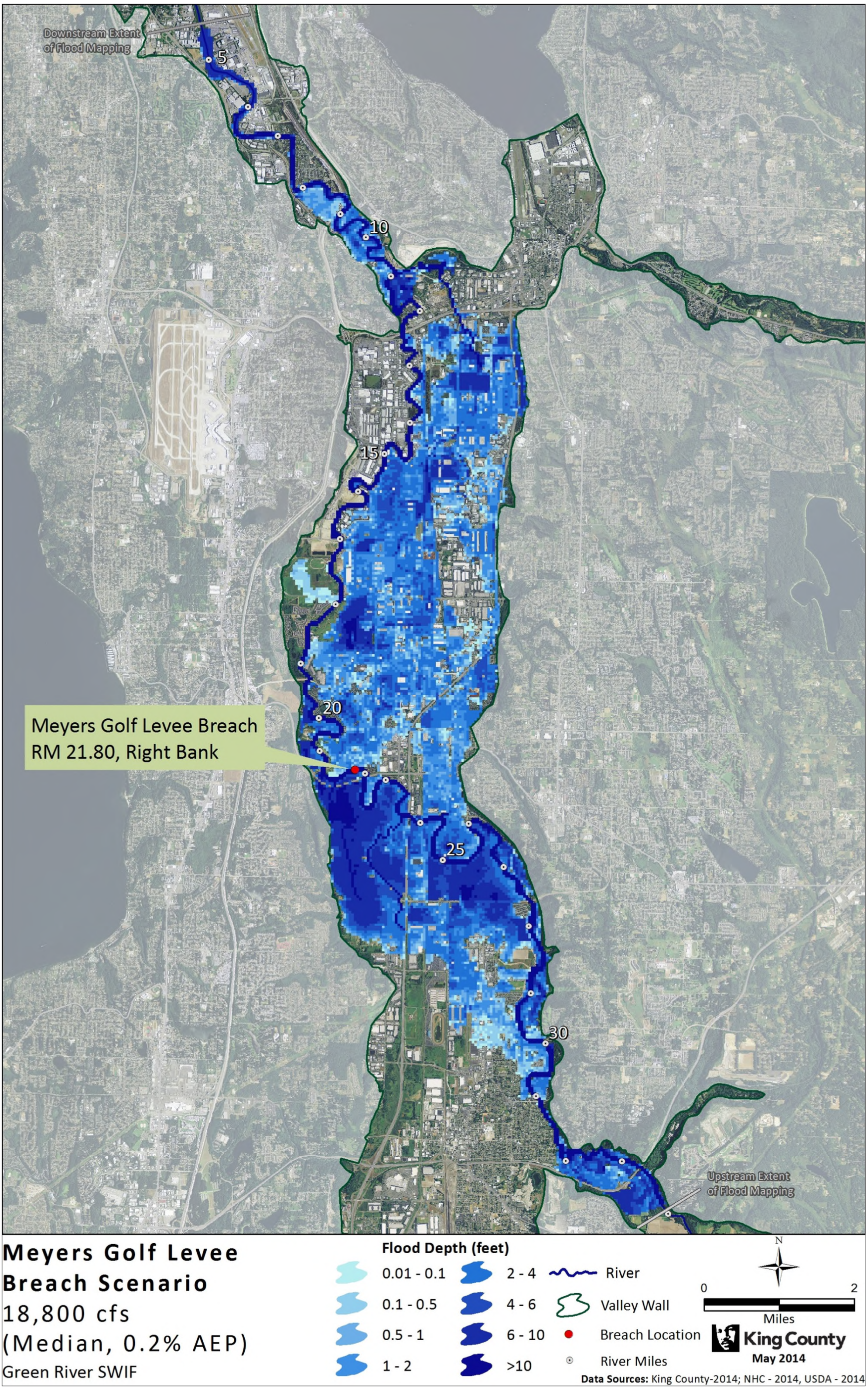


Figure 3-20 Inundation Map – Meyers Golf Course Levee Breach Scenario-18,800 cfs (Median, 0.2% AEP)

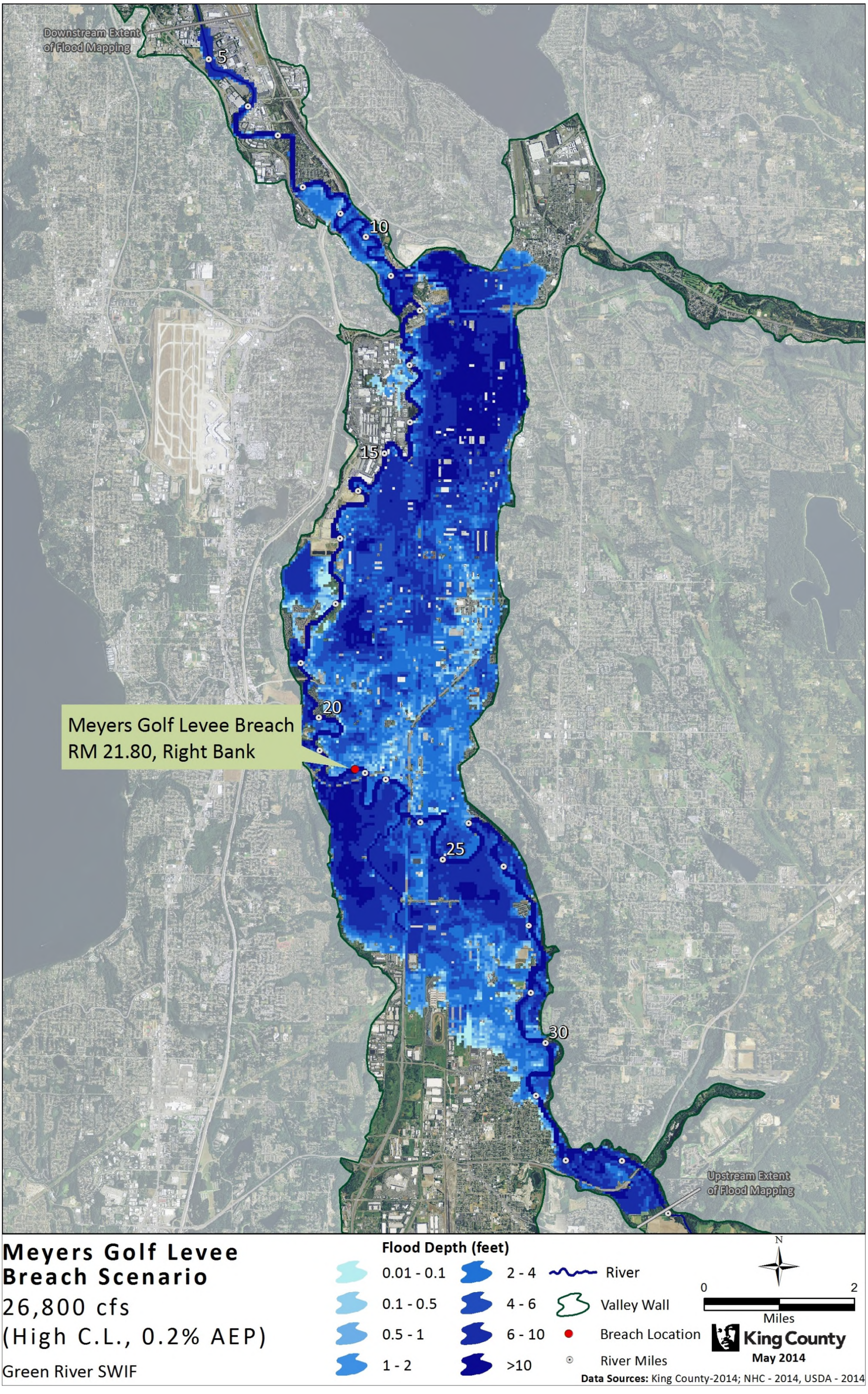


Figure 3-21 Inundation Map – Meyers Golf Course Levee Breach Scenario-26,800 cfs (High C.L., 0.2% AEP)

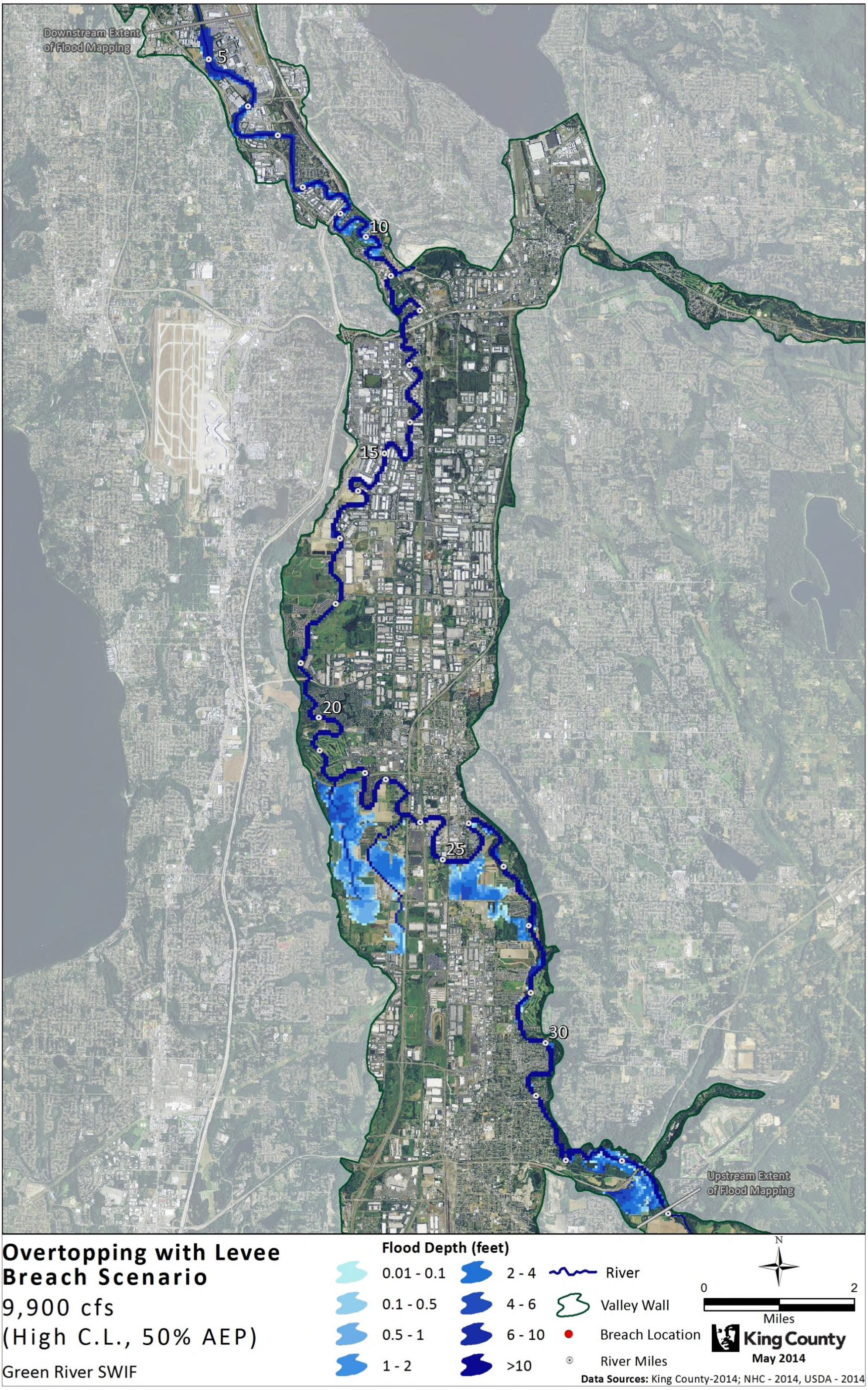


Figure 3-22 Inundation Map – Levee-Overtopping-Then-Breach Scenario-9,900 cfs (High C.L., 50% AEP)

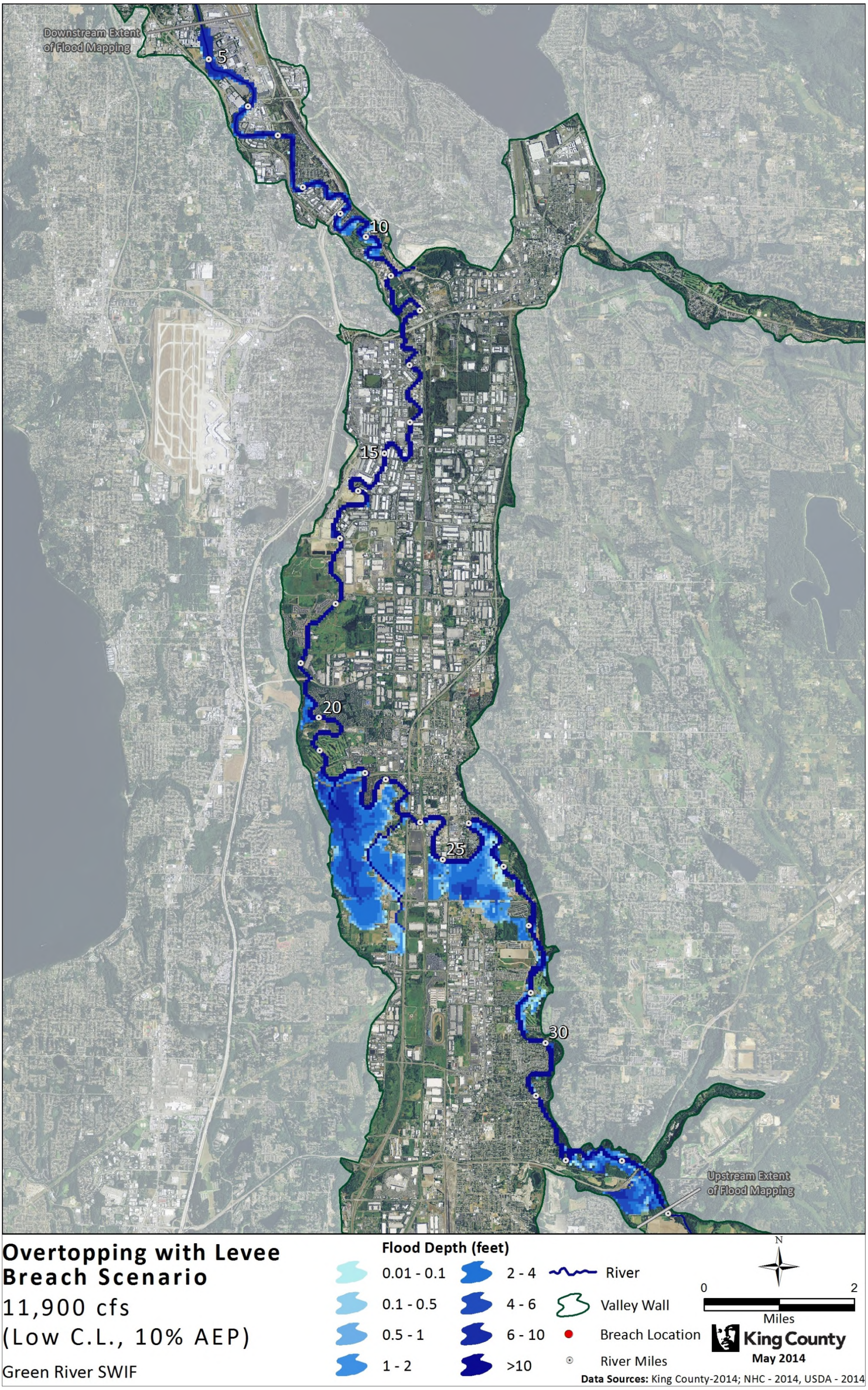


Figure 3-23 Inundation Map – Levee-Overtopping-Then-Breach Scenario-11,900 cfs (Low C.L., 10% AEP)

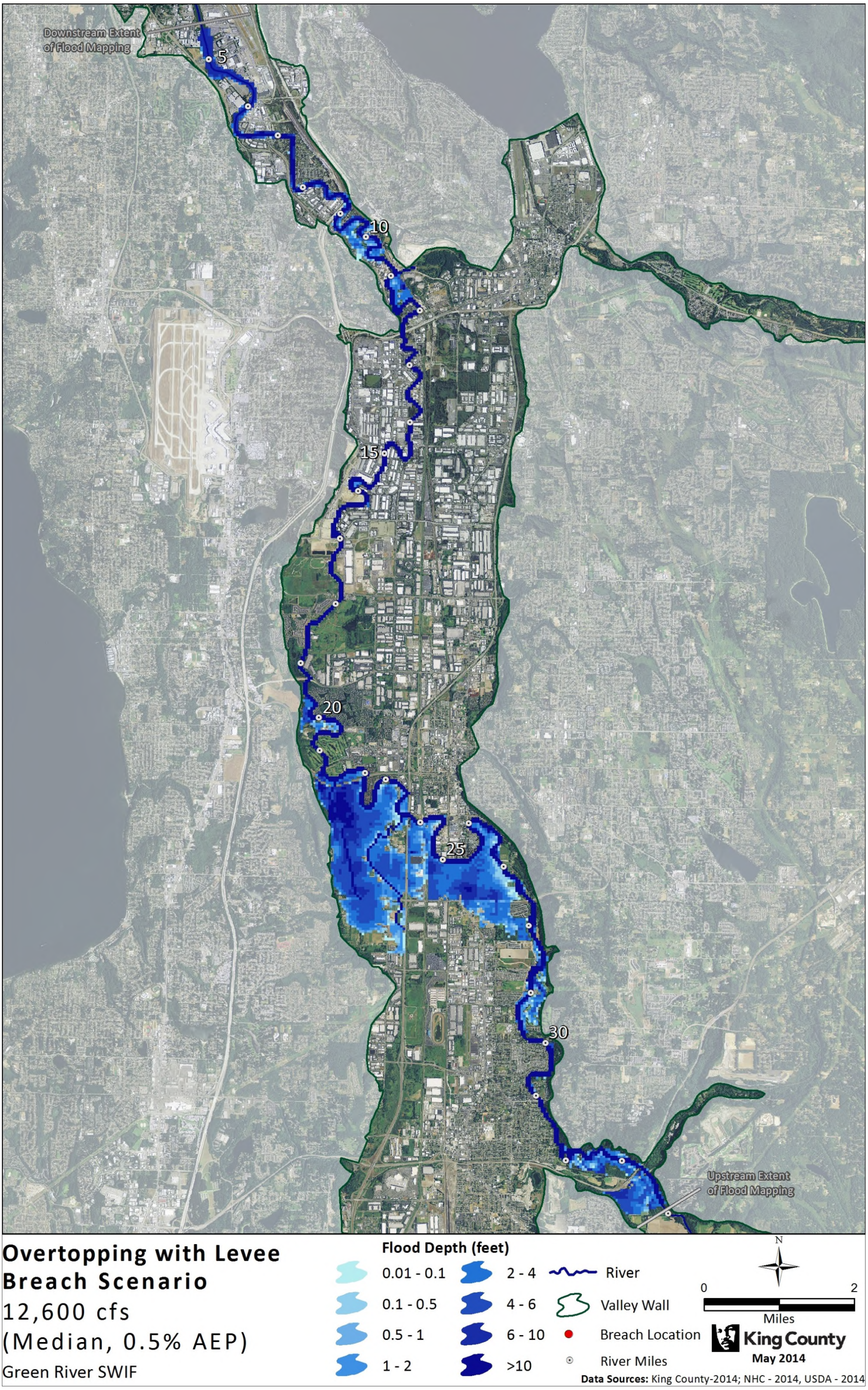


Figure 3-24 Inundation Map – Levee-Overtopping-Then-Breach Scenario-12,600 cfs (Median, 0.5% AEP)

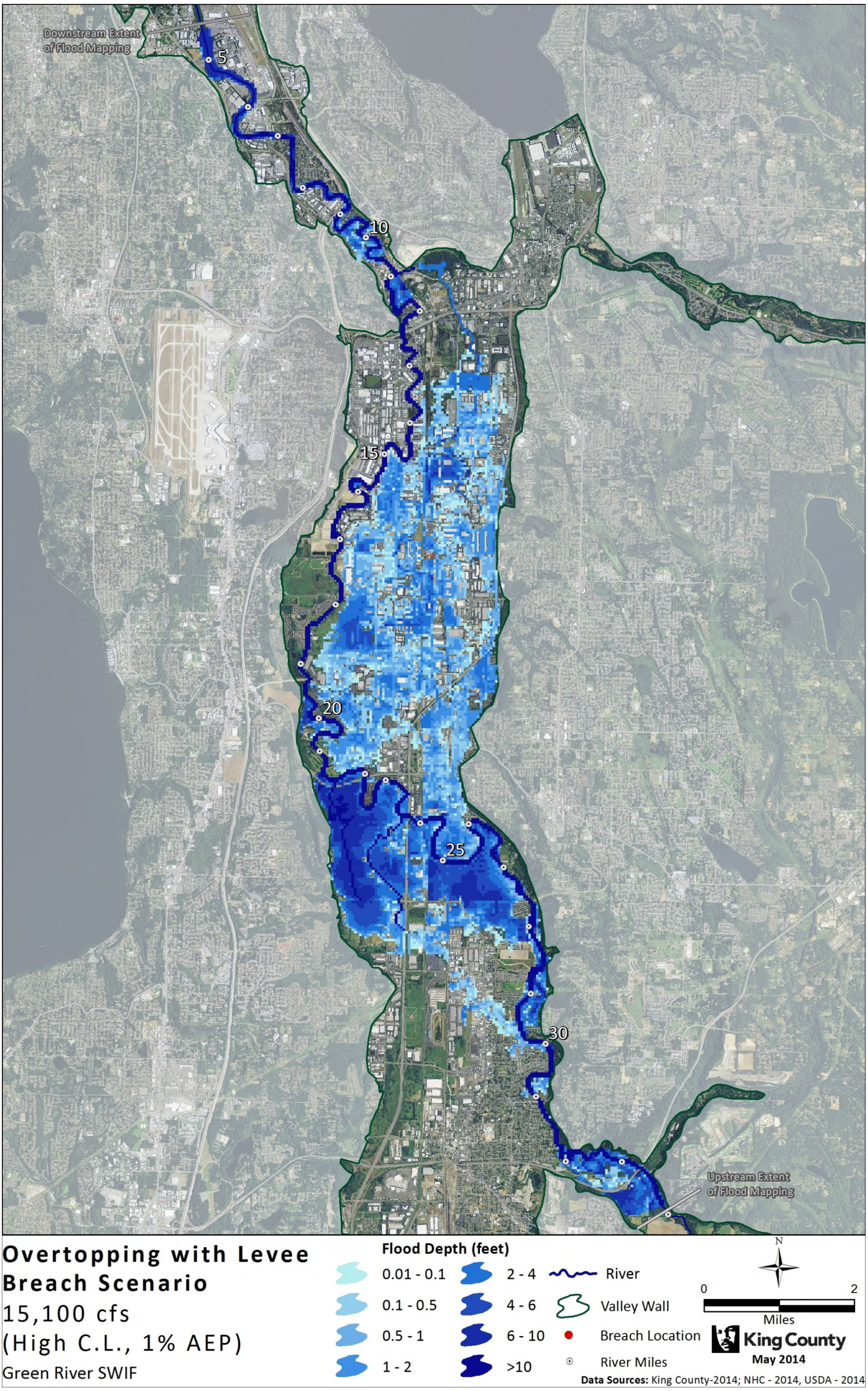


Figure 3-25 Inundation Map – Levee-Overtopping-Then-Breach Scenario-15,100 cfs (High C.L., 1% AEP)

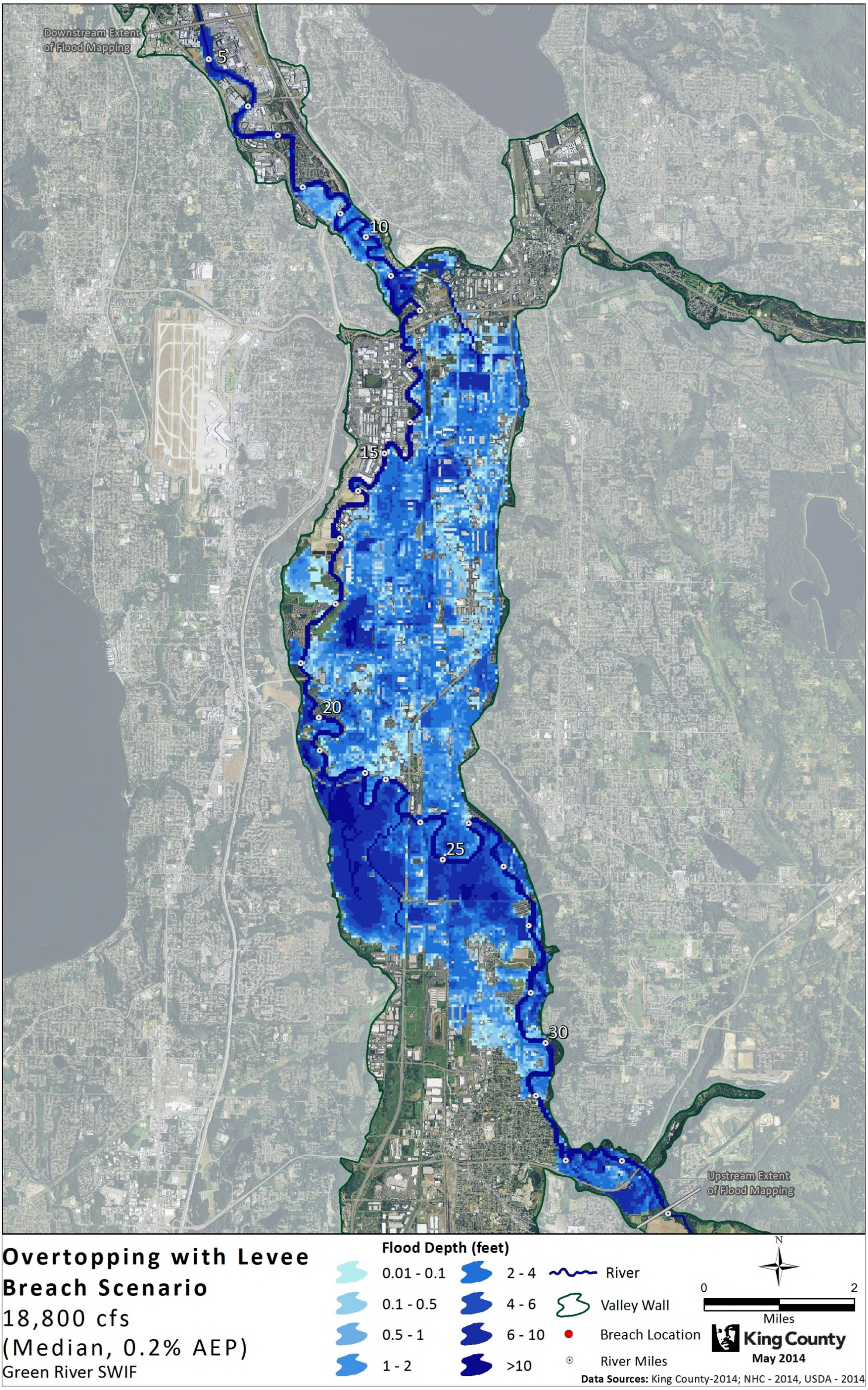


Figure 3-26 Inundation Map – Levee-Overtopping-Then-Breach Scenario-18,800 cfs (Median, 0.2% AEP)

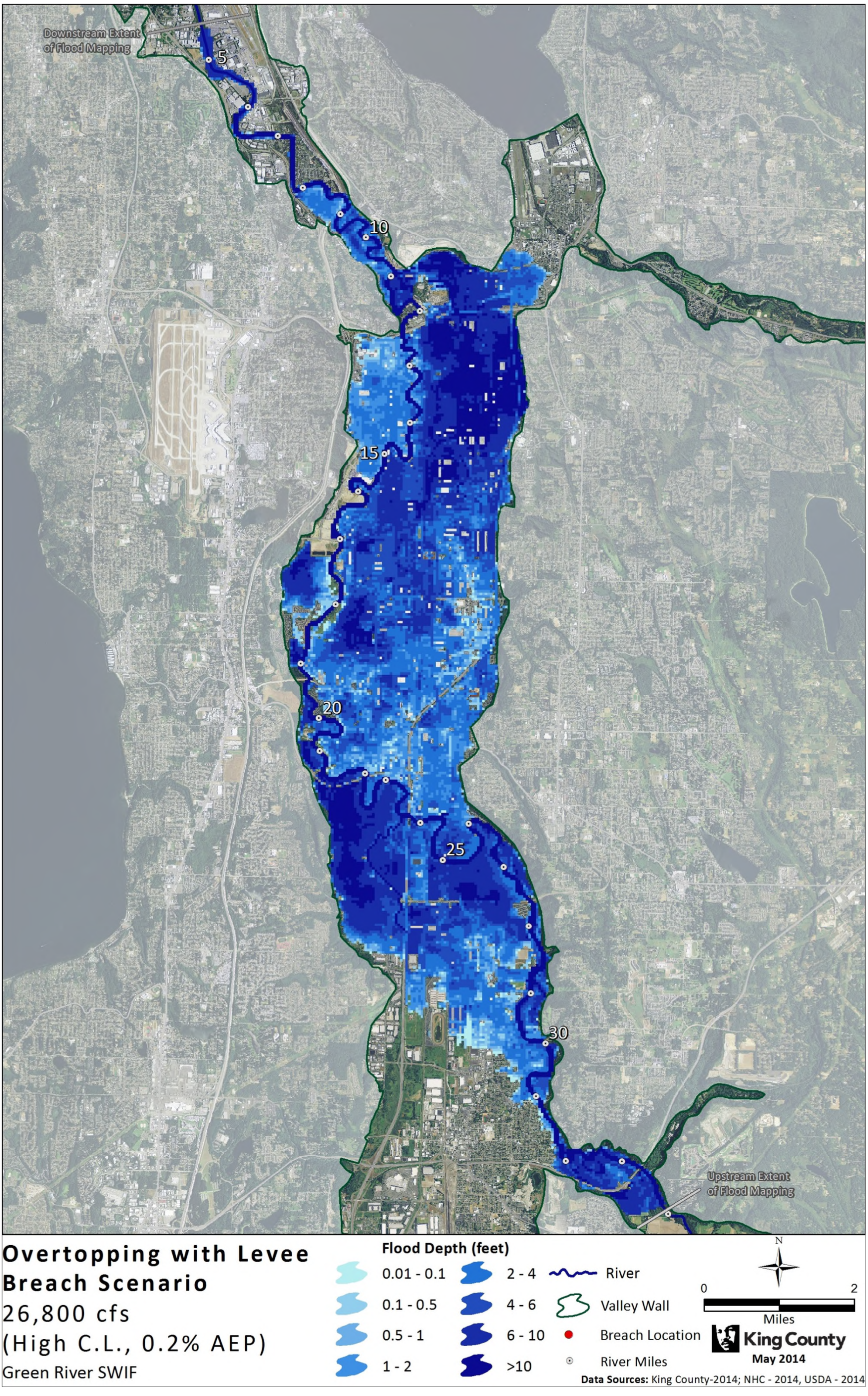


Figure 3-27 Inundation Map – Levee-Overtopping-Then-Breach Scenario-26,800 cfs (High C.L., 0.2% AEP)

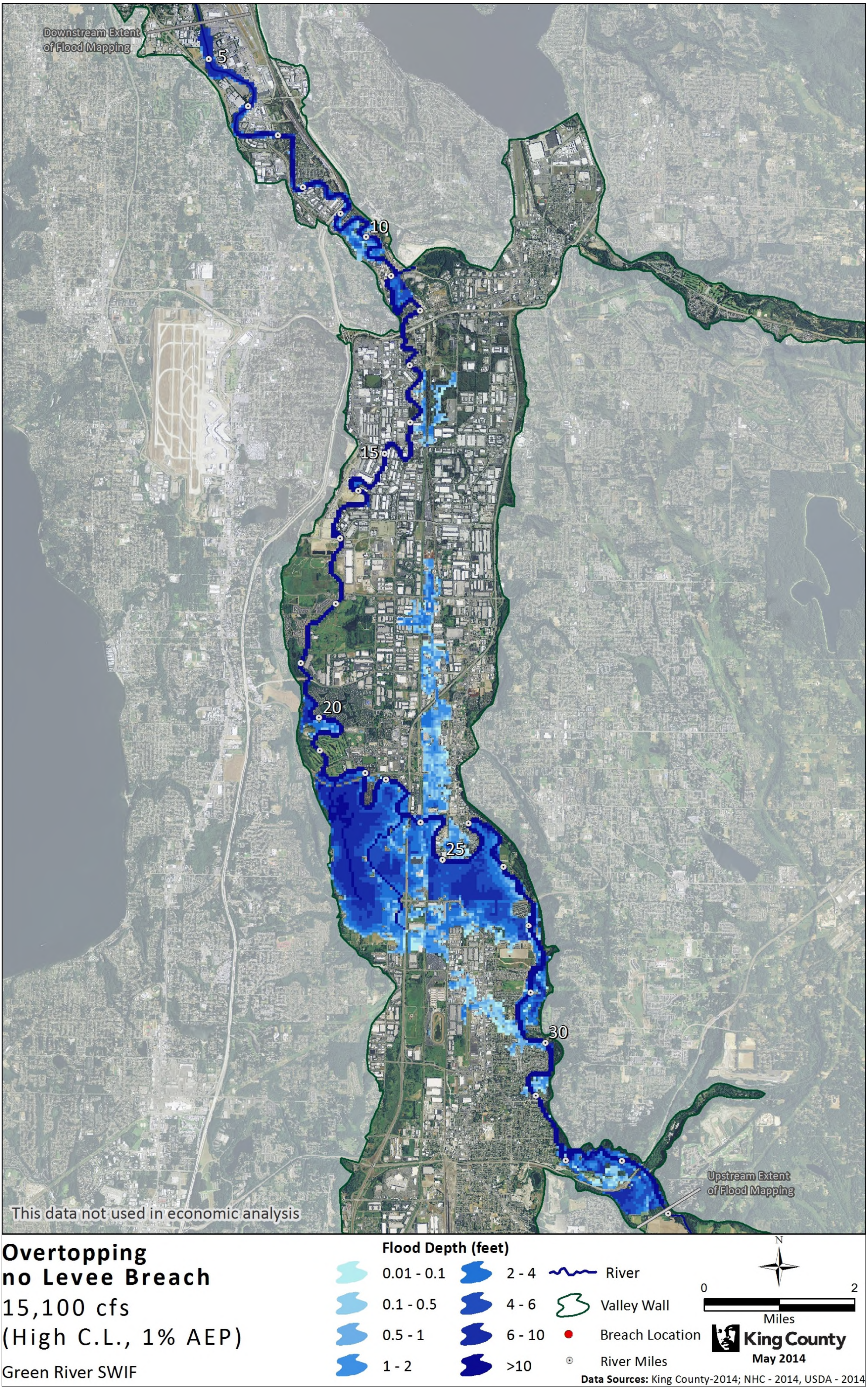


Figure 3-28 Inundation Map – Overtopping-No-Breach-15,100 cfs (High C.L., 1% AEP)

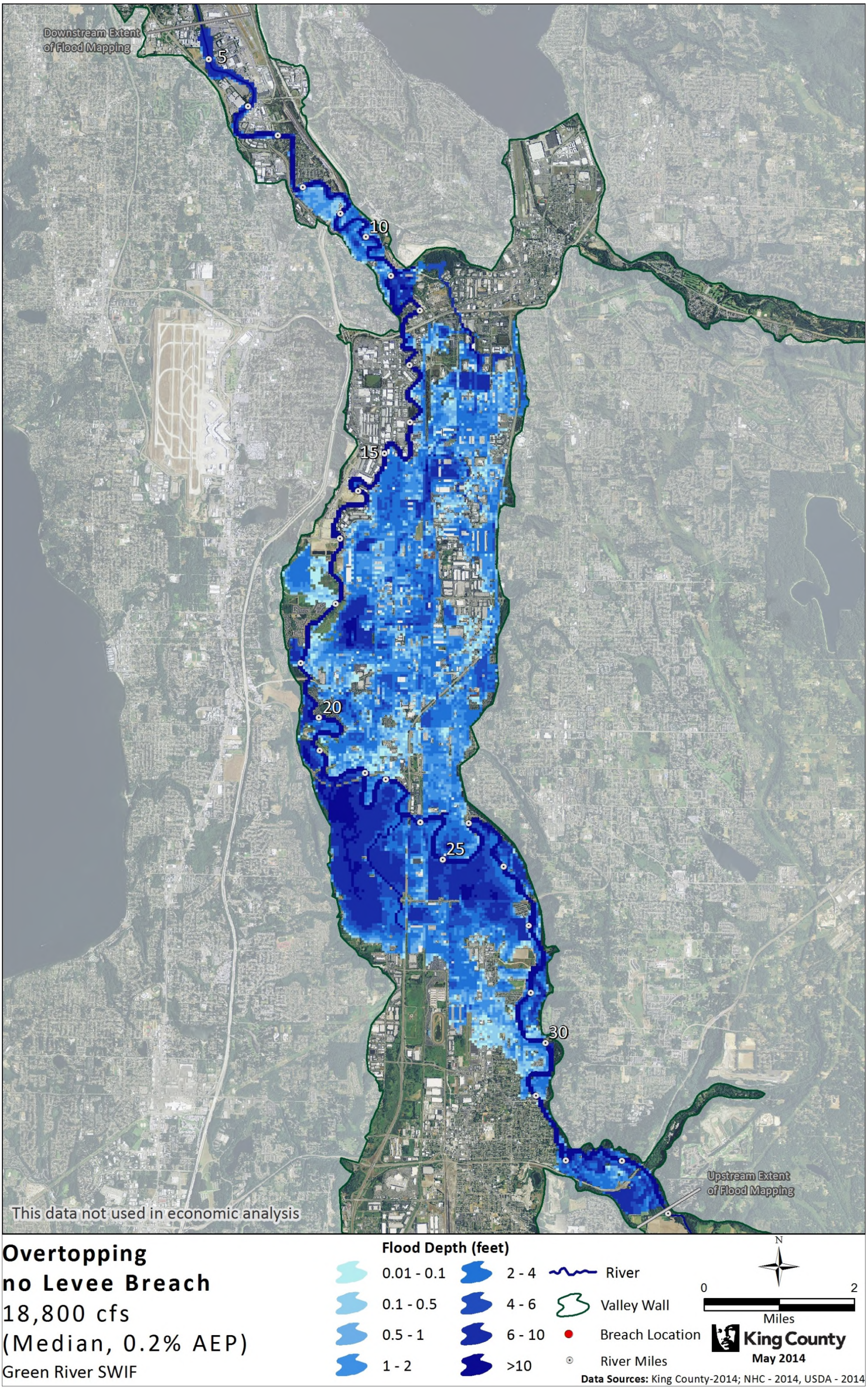


Figure 3-29 Inundation Map – Overtopping-No-Breach-18,800 cfs (Median, 0.2% AEP)

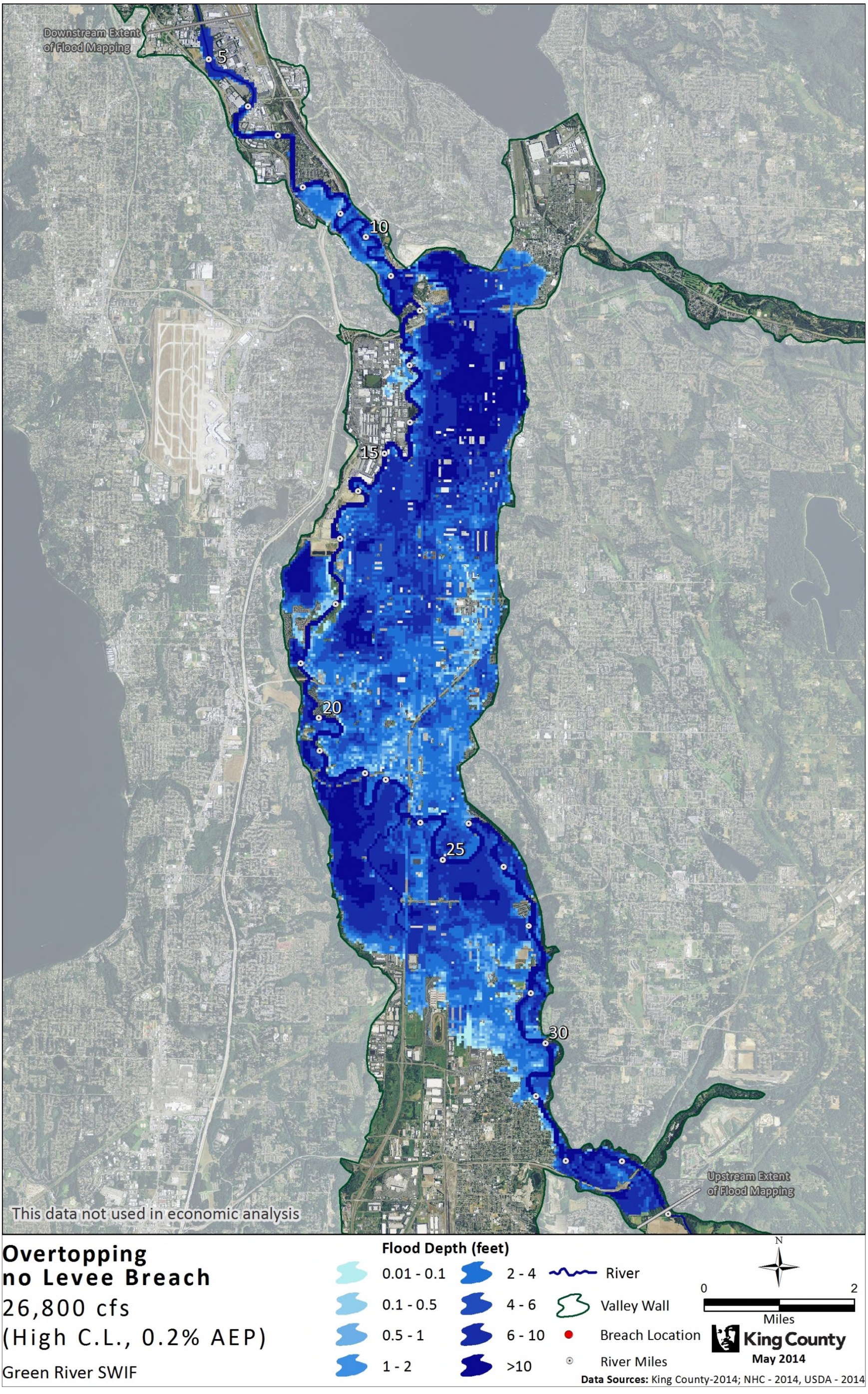


Figure 3-30 Inundation Map – Overtopping-No-Breach-26,800 cfs (High C.L., 0.2% AEP)

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King County

# GREEN RIVER, KING COUNTY, WASHINGTON
# SYSTEM WIDE IMPROVEMENT FRAMEWORK (SWIF)

Photo Credit: King County

## ATTACHMENT E:
## ECONOMICS TECHNICAL MEMORANDUM

**FINAL**

**MAY 2014**

# GREEN RIVER SWIF

# CURRENT CONDITIONS REPORT

# ECONOMICS TECHNICAL MEMORANDUM

**FINAL**

**MAY 2014**

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# 1. INTRODUCTION

## 1.1. PURPOSE AND SCOPE

This economics technical memorandum summarizes the objectives, methods, and results of the Existing Condition Economic Analysis for the Green River System Wide Improvement Framework (SWIF). The economic analysis is one element of the multi-discipline SWIF study focused on evaluating existing levee conditions and vulnerabilities. The economic analysis combines the findings of the geomorphic, geotechnical, and hydraulic analyses with an inventory of floodplain infrastructure in order to characterize existing condition flood risk.

The Green River SWIF project area extends from Howard Hanson Dam (HHD), located at river mile (RM) 64.5 downstream to the upper reaches of the Duwamish River, at approximately RM 5.5. The focal geography of the SWIF is the upper Duwamish and Lower Green River portion of the watershed, from approximately RM 5.5 to RM 32. Within the focus area there are approximately 18 miles of levee systems, of which five systems are PL 84-99 eligible levees between RM 12.4 and 30.8. Hydraulic analyses conducted for this SWIF provide critical input to the economic analysis. The hydraulic modeling focuses from RM 33 to RM 5.5 and reflects operation of HHD for flood risk management.

The purpose of this economic analysis in the Green River System Wide Improvement Framework (SWIF) project is to:

- Apply a multi-disciplinary risk-based approach to account for uncertainties in hydrologic, hydraulic, geotechnical and economic parameters.
- Utilize these multi-disciplinary inputs to develop estimates of flood risk in the system on an expected annual damage (EAD) basis.
- Characterize the range and types of flood damage impacts that might occur in the valley across varying magnitude flood events.
- Provide information to policymakers seeking to define an optimal level of protection for different reaches of the Lower Green shoreline.
- Provide an analysis framework for evaluating the effects of proposed flood risk management alternatives.

## 1.2. SETTING

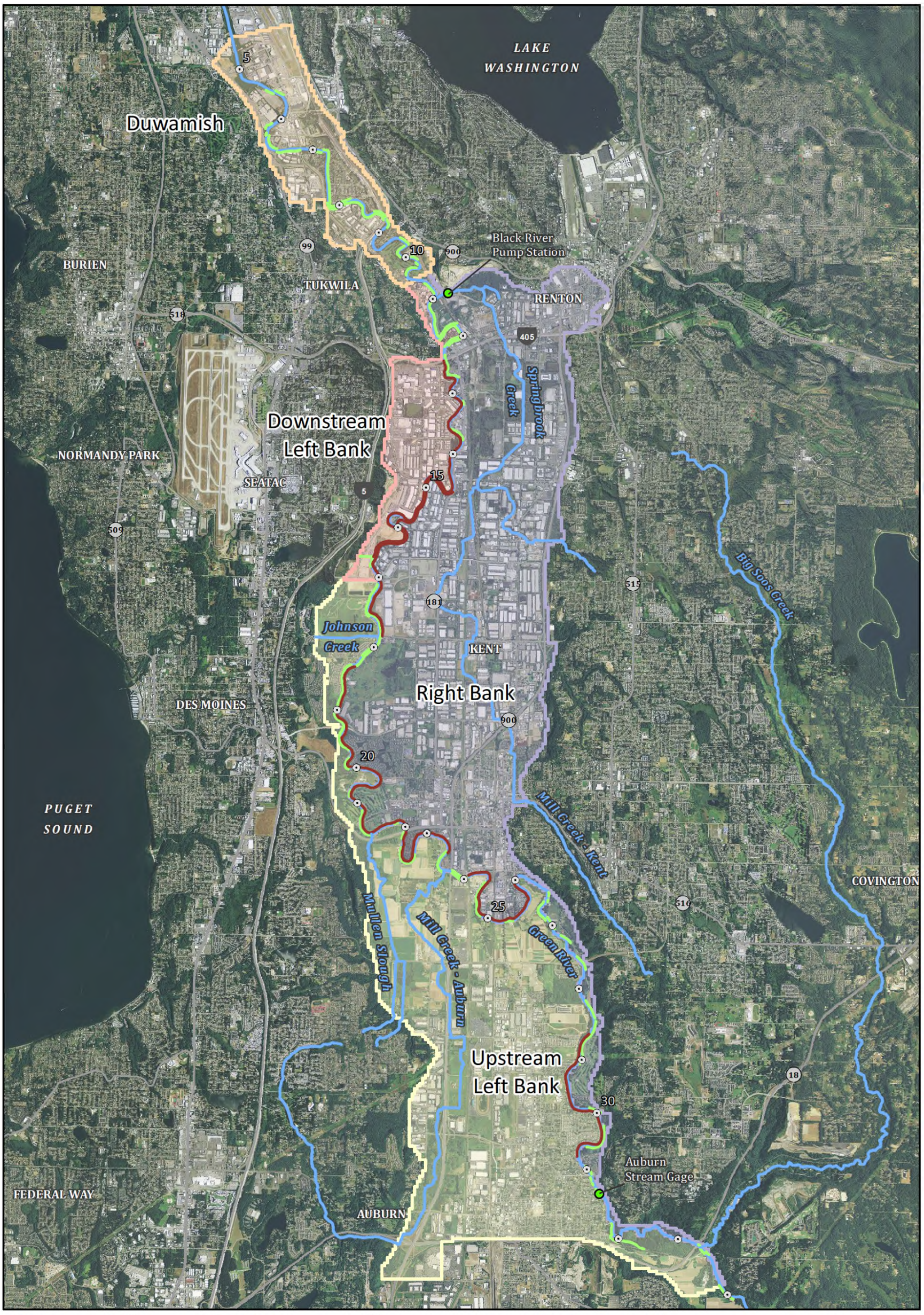
The study area begins at State Route 18 (SR18) bridge crossing, or river mile (RM) 33.25 and extends downstream to approximately RM 5 (place names and features described in the following narrative are shown in Figure 1-1. The river occupies a mostly undeveloped floodplain downstream of SR18 until reaching the City of Auburn. Soos Creek, the largest tributary on the Lower Green River, enters from the north at RM 33.32. Nearing Auburn, the river enters the Auburn Narrows, where it is confined between the White River alluvial fan and the eastern valley wall. The USGS Green River stream gage near Auburn (12113000) is located in the narrows at RM 31.28. This gage serves as the flow regulation point for HHD and is the standard location where Lower Green River flows are referenced.

For the economic analysis, the floodplain was divided into four economic modeling areas to assess flood impacts and damages between RM 33.25 and RM 5.5. These damage areas follow logical divisions in

levee systems and flood patterns (see Figure 1-1). The damage areas are referred to by the name of main cities within each one; however, they do not follow municipal boundaries. These names include the Auburn damage area (upstream left bank), the Kent/Renton damage area (right bank), the Tukwila damage area (downstream left bank), and the Duwamish damage area (furthest downstream area on both banks). The economic inventory within each damage area is discussed in subsequent sections of the memorandum.

## 1.3. Structure of the Memorandum

The economic analysis is dependent upon the results of other analyses conducted for the SWIF, primarily the geotechnical and hydraulic analyses. Section 2 describes the levee failure analysis and how inputs from other disciplines inform and are incorporated into the economic analysis methodology, and the types of information resulting from the economic analysis. Section 3 discusses the risk (or damage) categories evaluated in the analysis. Section 4 discusses economic modeling in order to produce an expedited economic analysis of flood risk. Section 5 summarizes the results of the modeling and development of a system-wide estimate of expected annual damage. Section 6 summarizes potential benefits associated with two level of protection considerations, and Section 7 presents key findings and discusses limitations on the information presented.




# Green River SWIF

## Hydraulic/Economic Modeling Area

N

0 2
Miles

King County
May 2014

USACE PL 84-99 Levee Systems
Other Levees and Revetments
River Miles
Green River and Streams

Duwamish
Downstream Left Bank
Upstream Left Bank
Right Bank

Sources: King County-2014; USDA-2014

Figure 1-1. Economic Modeling Areas

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# 2. METHODOLOGY

The purpose of the Existing Condition Levee System Analysis is to characterize existing condition flood risk and vulnerabilities. The following outlines the approach and methods developed and used in support of the SWIF. The analysis serves as a baseline for the alternatives development and is intended to also provide information to support the level of protection goal setting that is underway. A key component of the Levee System Analysis is a levee failure analysis includes integration of geotechnical, geomorphic, hydraulic, and economic factors to characterize and quantify existing condition flood risk. The levee failure analysis considers potential breach locations along with overbank flooding and levee overtopping. Four existing condition scenarios were defined, modeled, and combined to characterize existing condition flood risk. Geotechnical and hydraulic parameters are inputs to the economic model which tabulates damage in the floodplain corresponding to various levels of flood stage then converts these estimates to an expected annual flood damage. The geomorphic, geotechnical, and hydraulic inputs are described in more detail in their respective technical memorandums.

The economic evaluation of flood risk is based on integration of an inventory of floodplain land use, structures, and contents, and infrastructure with geotechnical and hydraulic parameters that characterize the probability of flooding in the study area. The methodology relies on existing information, supplemented with updated hydraulic modeling and application of a new economic model to assess and quantify impacts. The damage estimates for each existing condition scenario were calculated using the latest version (1.25a) of the Corps of Engineers Hydrologic Engineering Center Flood Damage Assessment model (HEC-FDA) [Corps of Engineers 2014].The following subsections describe this methodology in more detail.

## 2.1. LEVEE FAILURE ANALYSIS

This section summarize key assumptions and inputs into the levee failure analysis and the economic evaluation of flood risk.

### 2.1.1. LEVEE CONFIGURATION AND ASSUMPTIONS

The current configuration, location and condition of flood risk reduction facilities, including the new and soon-to-be constructed facilities, including setback levees, flood walls, and secondary flood containment structures were included in the evaluation. These projects include modifications in Kent, Auburn and Tukwila as outlined in Table 2-1.

**Table 2-1. Included Levee Modifications**

| Project Name | River Mile Extents | Project / Plan Status | Description | Status |
|---|---|---|---|---|
| Reddington Setback Levee (LB) | 28.6-29.5 | Constructed 2013 | Levee setback | Construction complete |
| Reddington Extension (LB) | 28.2-28.6 | 90% Plans (2015 or 2016) | Levee setback | 90% design |
| Horseshoe Bend Levee (RB) | 26.0-26.2<br>24.25-24.50 | Constructed 2012-13<br>Constructed 2012-13 | Secondary levees and floodwalls | Construction complete |
| Foster Park Levee (RB) | 23.8-24.05 | Constructed | Secondary levee | Construction complete |
| Hawley Road Levee (RB) | 23.2-23.3 | In construction (2012-14) | Raised levee | Construction substantially complete |
| Upper Russell Road Levee (RB) | 20.1-20.4<br>19.5-19.8 | 100% Design (2014-15 construction)<br>Constructed 2013 | Secondary levee/setback<br>Secondary levee | 100% design, partially funded<br>Construction complete |
| Boeing Levee (RB) | 17.0-17.2 | Constructed in 2013 | Secondary levee and floodwall | Construction Complete |
| Briscoe-Desimone Levee (RB) | 16.9-17.0<br>16.0-16.4<br>15.45-15.6<br>14.5-14.6 | 30% Design (2015)<br>100% Design (2014)<br>100% Design (2014)<br>30% Design (2015) | Raised levee and floodwall<br>Floodwall and bench<br>Floodwall and bench<br>Floodwall and bench | 30% design, funded<br>100% design, funded<br>100% design, funded<br>30% design, funded |
| Segale/Tukwila Development (LB) | 16.7-17.3 | In construction (2012-2014) | Raised levee, floodplain fill, and stormwater pond/Johnson Creek excavation | Under construction |

### 2.1.2. Levee Failure Locations

Potential levee breach locations have been informed by geotechnical, geomorphic hydraulic and economic factors. Geotechnical assessment focused on the PL 84-99 levee systems and synthesis of previous work to identify potential breach locations. Geomorphic considerations included assessment of channel bed incision points to identify other potential vulnerable areas. Hydraulic and economic factors included geography and inundation patterns along with development patterns which resulted in four damage reaches or areas, as defined in Figure 1-1. King County staff also completed a field investigation of known vulnerabilities to assist in identifying priority sites for the hydraulic modeling.

#### 2.1.2.1. Geotechnical Considerations

Levee reconnaissance ratings from previous studies between for PL 84-99 levee segments between RM 6.3 and 32 were utilized to evaluate vulnerability to failure for the levee failure analysis and to develop potential breach locations for preliminary evaluation. This was achieved by calculating a weighted reconnaissance score considering the attributes of levee geometry, revetments and erosion (excluding animal signs because of limited exposures), and channel direction and depth. Fifteen preliminary breach locations were identified through this process to be considered for further evaluation by the project team.

Using the preliminary breach location data and previous experience with the Green River levees, the project team of King County, Tetra Tech, and NHC selected six potential breach locations where fragility curves would be developed to support the levee system analysis and characterization of flood risk. The locations of the potential breach locations are shown in Table 2-2. Fragility curves were developed at each of these locations.

**Table 2-2. Selected Potential Breach Locations**

| Potential Breach No. | Levee Reach | River Bank | River Mile |
|---|---|---|---|
| 1 | Dykstra | Left | 30.69 |
| 2 | Tukwila 205 | Left | 14.83 |
| 3 | Horseshoe Bend | Right | 25.50 |
| 4 | Meyers Golf | Right | 21.80 |
| 5 | Lower Russell Road | Right | 18.60 |
| 6 | Briscoe-Desimone | Right | 16.62 |

Of the six potential breach locations, only Tukwila 205 has a previously developed fragility curve. Fragility curves were developed at the remaining five locations by comparing the levee geometry including the levee height, slope inclinations, base width, crest width, and the slope gradient beyond the landside toe to the levee geometry of the existing fragility curves. Each of these geometric conditions strongly influence the failure modes. Topographic information at each breach location was obtained from County obtained 2006 topographic survey. Levee geometry at each of the breach locations is provide in the Geotechnical Technical Memorandum (2014).

Geometric comparisons were made when considering the most influential failure mode, including:

- slope gradient landward of the toe and levee height when considering underseepage influence
- riverside slope inclination when considering the seismic influence, and
- riverside slope inclination and levee height when considering rapid drawdown

The composite probability of failure at the river stage of 1 foot above the levee toe, and 1 foot below the levee crest for the most similar levee section was utilized to develop the new fragility curve. In addition to developing the composite probability of failure by comparing geometry and probability of failure modes, the maximum probability of failure previously generated for all breach locations was developed. To validate the empirical fragility method, a new fragility curve was generated for one of the existing curves using only the levee geometry and comparing the conditions to the existing probability of failure curve data. The results were consistent with the existing curve data that was generated by the Taylor's Series Mean Value Method. Following fragility curve development, four breach locations were selected by the project team for inclusion in the system-wide levee scenarios as part of the flood risk analysis tasks.

#### 2.1.2.2. Geomorphic Considerations

From a geomorphic perspective, damage and potential failures along focus area levees and revetments are most likely caused by bank erosion and streambed scour. The method used to assess potential bank erosion and bed scour sites included evaluation of time series aerial photographs available on the Google Earth website, and review and comparison of channel cross sections developed for hydraulic modeling. The aerial photographs reviewed included those dated 1986, 1990, 2002, 2003, 2004, 2005, 2006, 2009, 20010, 2010, 2011 and 2012. The hydraulic model cross sections were surveyed for use in three different flood studies dated 1986, 2006 and 2011; the cross section from each flood study were positioned at the same, or nearly the same, river mile stations.

Comparison of the time series aerial photographs and cross sections indicates whether the channel banks and bottom changed appreciably over the periods of record. Particularly useful to identifying the locations of potential levee failure sites is the comparison of channel cross sections. The comparative evaluation is based on the premise that vertical changes in the elevation of the channel floor indicate aggradation of the streambed due to sediment deposition, or a degradation of the streambed due to erosional scour (incision).

The comparison of the cross-section data shows a decrease in the elevation of the stream bed below river mile 24.0 from 1986 to 2011, clearly indicating that the stream bed has been primarily subject to erosion and incision. Upstream of river mile 27.0, the river bed has been fairly stable. Aerial photographs were reviewed for, but provided no visual evidence of, local aggradation, such as sustained and/or growing mid-channel or point bars in between cross section locations.

Streambed scour poses a potentially significant risk of undermining the toes of levees and revetments, which can cause unraveling of levee/revetment materials. Potential levee sites subject to failure due to streambed scour were evaluated using the comparison of channel cross sections. For the evaluation, cross sections from 1986 and 2011 were used to identify river mile stations where the bed elevation decreased 5 feet or greater. Five feet was selected as the threshold value because it is sufficiently deep to intercept most of the Lower Green River levees. The principle results of this evaluation are shown on Figure 2, 'Significant Incision Point Location Map' in the Geomorphic Technical Memorandum. Results of the cross section evaluation were also compared against levee and revetment damage sites derived from the Green River Repair Sites Master List (2014) the findings of which can be found in the Geomorphic Technical Memorandum.

While the cross-section evaluation and review of the damage sites was informative, geotechnical considerations combined with site visits by County staff offer more pivotal considerations in identifying potential breach locations for hydraulic modeling. Correlation between damage sites and incision points should be evaluated further as the SWIF planning process moves forward.

#### 2.1.2.3. Hydraulic Modeling Considerations

Preliminary Flo-2D model results were used as one component in the selection process of breach locations, primarily to ensure that selected locations would be representative of overall flooding patterns.

Results from a City of Kent levee certification analysis conducted by NHC in 2010 and other prior model results involving breach simulations throughout the levee system were used to gain an understanding of what areas a breach in a given segment would inundate. In general, the floodplain area closest to the breach was more likely to only be inundated by the nearby breach, while the floodplain area farther downstream could be inundated by breaches from multiple locations. GIS analysis was used to map the number of different breaches that inundated a given floodplain cell. Areas of extensive inundation with a single breach source were identified and used as one parameter in the breach selection process.

Another breach location decision was whether the Briscoe-Desimone or Meyers Golf Course levees should be selected for the second breach location into the Kent/Renton damage area (Horseshoe Levee being the site of the first selected breach into this area). Both locations were simulated with an approximate breach and results compared. The simulations showed the Meyers Golf Course breach inundated a large upstream area, as well as most of the area the Briscoe-Desimone breach flooded. Based on this finding, the Meyers Golf Course breach was selected for the inundation analysis.

#### 2.1.2.4. Socio-Economic Considerations

One of the criteria in selecting breach locations was to ensure that all potential areas that could be inundated were reflected in the selection of breach locations for the economic evaluation. The preliminary hydraulic modeling noted above supported this consideration and also helped in defining the economic damage areas.

Flood risks are not limited to economic impacts and damage but also include life safety risks. Given the highly developed nature of the Lower Green River Valley the potential for loss of life related to flooding is significant. Life safety risk is further heightened when associated with levee breaches. Although life safety is of paramount importance, incorporating loss of life into the Current Condition Levee System Analysis was not possible with the selected models and beyond the scope of this technical memorandum.

## 2.2. Existing Condition Scenario Development

As described above, four existing condition scenarios were developed based on the combined project team efforts. The project team identified four representative levee breach locations which would allow characterization of flood risk throughout the four identified damage areas. Through subsequent hydraulic analysis to determine the relative independence of the identified breach locations, the four breach locations were combined into three scenarios. These three scenarios allowed for breach prior to the levee crest being overtopped, and so are referred to as the levee breach scenarios. The fourth existing condition scenario was modeled as an overtopping scenario without levee breach prior to the crest being overtopped, and so is referred to as the levee-overtopping-then-breach scenario. These scenarios are intended to characterize the range of possible existing conditions that might occur. By modeling each scenario independently, their results may be combined probabilistically via post processing to generate a reasonable estimate of system-wide expected annual damages without explicitly modeling every possible levee failure location scenario.

### 2.2.1. Levee Breach Scenarios

Three levee breach scenarios were included in the economic modeling. These are:

1. **Tukwila / Dykstra Levee Breach**
    a. This scenario breaches at the Tukwila (RM 14.83) and Dykstra (RM 30.69)levees on the left bank, corresponding to the Auburn damage area and the Tukwila damage area. It reflects the risk of a geotechnical/breach failure occurring prior to water reaching the levee crest.
2. **Horseshoe Bend Levee Breach**
    a. This scenario breaches at the Horseshoe Bend levee (RM 25.50) on the right bank, corresponding to the Kent/Renton damage area. It reflects the risk of a geotechnical/breach failure occurring prior to water reaching the levee crest.
3. **Meyers Golf Levee Breach**
    a. This scenario breaches at the levee near Meyers levee (RM 21.80) on the right bank, corresponding to the Kent/Renton damage area. It reflects the risk of a geotechnical/breach failure occurring prior to water reaching the levee crest.

### 2.2.2. Levee-Overtopping-then-Breach Scenario

In addition to the three levee breach scenarios described above, a fourth scenario, levee-overtopping-then-breach, was modeled to simulate levee overtopping without the hydraulic influence of a levee breach at the breach locations. This scenario provides an understanding of flood risk and damages of the levee system without assuming a geotechnical based levee breach. The scenario allows for a plausible evaluation of how the system would respond without levee failure.

In considering levee system performance under overtopping conditions it was the consensus of the project team that once overtopped, the levees were much more likely to breach than to remain intact. As such the hydraulic model output was modified to reflect expected water surface elevations in the floodplain to correspond to the team's view that breaches will likely occur when the levee is overtopped. Further details on the inundation depths used for this scenario are included in the Hydraulics Technical Memorandum.

## 2.3. Hydraulic Modeling in Support of Scenarios

The fragility curves developed for the selected four levee breach locations were necessary inputs to the hydraulic and the economic modeling of the three failure scenarios. The breach parameters of the FLO-2D hydraulic model were informed by the fragility curves, the fragility curves are used directly in the HEC-FDA software, and the fragility curves inform the system-wide scenario weighting (see Section 2.5). See Section 2.1.2.1 and the Geotechnical Memorandum for further detail.

Hydraulic modeling was performed in FLO-2D to generate a set of floodplain depth grids for a range of flows for each of the four existing scenarios. The selection of hydrographs used in the FLO-2D modeling was a subset of the 2012 Corps of Engineers evaluation of design flood hydrographs for the Green River basin (Corps of Engineers 2012) which was judged to best represent the range of floods that might occur in the heavily regulated system. The hydraulic modeling incorporates flood volume to estimate inundation depths in the floodplain. The resulting depth grids were provided for incorporation into the HEC-FDA model. See Section 3.6 of the Hydraulics Technical Memorandum for further detail on the development of the fragility curves.

The HEC-FDA economic model requires identification of the stage-discharge relationship at an index location for each damage area. Additionally, it allows for the inclusion of uncertainty about the exceedance-discharge and stage-discharge function. Section 3.7 of the Hydraulic Technical Memorandum describes development of the index location relationship and the system-wide estimate of stage uncertainty. Uncertainty about the exceedance discharge curve is discussed further in Section 4.1.1 of this memo.

## 2.4. Economic Model Runs

As noted above, HEC-FDA was the primary economic model. Additional economic model inputs were incorporated from FEMA's HAZUS model guidance documentation (FEMA 2014), which is an event-based flood damage model that contains default inventories and damage functions. Use of HAZUS model base data and damage functions is incorporated into discussion of damage categories in Section 3. Additionally, estimation of regional economic impacts of flooding was carried out in the regional input-output model Impact Analysis for Planning (IMPLAN) [MIG 2014]. Integration of IMPLAN model outputs into HEC-FDA is discussed in more detail in Section 4.

## 2.5. Scenario Weighting

Each of the four existing condition scenarios was modeled independently to assess system-wide flood damages under each. Thus, in order to create a single estimate of expected annual damage for the system, the expected annual damage results for each scenario needed to be combined consistent with the likelihood of each scenario occurring. Combination of these scenarios was accomplished on a weighted basis by calculating the independent probability of occurrence for each scenario and then normalizing these probabilities relative to each other. This section describes the weighting methodology. Section 5 summarizes the results of the economic models and the calculation of system-wide expected annual damage.

For each scenario, the calculation of probability of occurrence is summarized in Table 2-3 and explained graphically in Figure 2-1. As shown in Figure 2-1, the probability of occurrence for each scenario was based on a generalized estimate of the area underneath the fragility curve. This calculation effectively accounts for the risk of breach below the levee crest as well as the certainty of breach once the levee is overtopped, or alternatively stated, the estimated annual probability of a failure occurring across the full range of stage elevation in each damage area.

In the three levee breach scenarios, all damages are triggered by geotechnical failure of the levee associated with that scenario. The fragility curves developed as part of the geotechnical assessment for the four selected breach locations were incorporated into HEC-FDA for levee failure modeling. The fourth scenario, levee-overtopping-then-breach, is necessary to characterize flood risk throughout the system from water escaping the channel (areas with and without existing levees) independent of whether a levee breach has occurred below the crest. This scenario can be represented conceptually by a fragility curve with a vertical straight line from 0% to 100% failure probability at the levee crest stage elevation (see Figure 2-1). Doing so illustrates that the same probability of occurrence calculation can be completed for this scenario as the levee breach scenarios.

As shown in Table 2-3 and Figure 2-1, the project team used the fragility curves to develop consistent assumptions for calculating the probability of occurrence for each scenario (based on the median or 50% C.L. flow curve). The “trigger elevation” for levee breach was defined as a water surface elevation 1-foot above the landward toe of the levee, which corresponded to an inflection point in the fragility curve at a 2% risk of failure. The hydraulics team then provided the corresponding flow’s annual exceedance probability (AEP). Similarly, the AEP of the flow that initiates overtopping in the damage area was estimated at the low point along the bank in each damage area. This low point which initiates overtopping corresponds to a 100% failure risk on the fragility curve.

Using these values, the area underneath the curve was estimated as shown in Figure 2-1. The column headings in Table 2-3 correspond to the annotations on Figure 2-1 in order to illustrate the calculation. The section labeled **D** in the area under the curve is approximated as a rectangle, where the width of the rectangle is the AEP of the breach trigger (point **A**) less the AEP of overtopping initiation (point **B**) and the height is the risk of failure at the trigger elevation (point **C**). The frequency (probability of occurrence) associated with point **A** and **B** is based on the median C.L. (median) flow curve. The section labeled **G** is calculated as a rectangle as well, where the width is AEP of initiating overtopping (point **B**) less AEP of maximum stage [the limit of which approaches an AEP of zero (point **E**)], and where the height is the risk of failure at the point where overtopping initiates (point **F**). Values in Figure 2-1 correspond to the Horseshoe Breach row in Table 2-3. Calculation of the probability of occurrence for each scenario results in the values shown in the second to last column of Table 2-3.

To normalize the four independent probabilities, the values were summed to calculate the percent of that sum that each scenario represents, as shown in Table 2-4. These four weighting factors were used to weight each individual scenario's expected annual damages to yield a single system-wide expected annual damage. Note that because the Tukwila and Dykstra breach locations are included in the same scenario, the Tukwila breach statistics were selected to represent the scenario, as the Tukwila breach has a far larger likelihood of occurrence.

This methodology results in a weight of 17% for the levee-overtopping-then-breach scenario, a weight of 33% for the Tukwila / Dykstra breach scenario, a weight of 23% for the Horseshoe Bend breach scenario, and a weight of 27% for the Meyers Golf breach scenario.

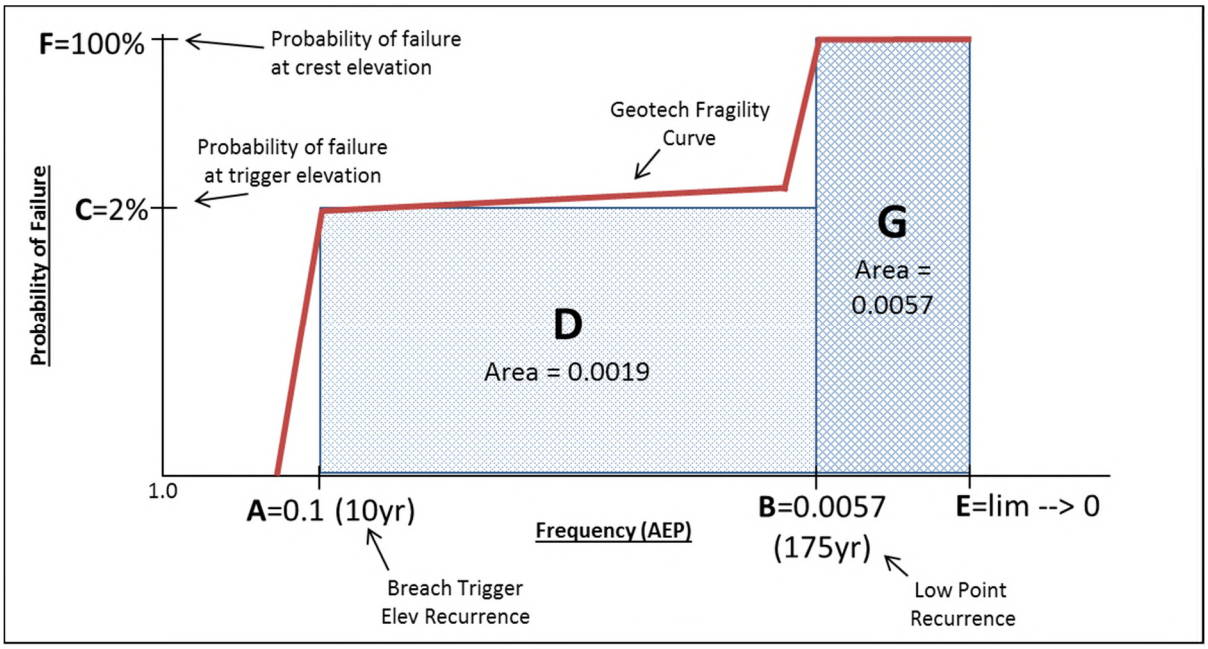


**Figure 2-1. Weighting Calculation Example for Horseshoe Levee Breach**

**Table 2-3. Scenario Weighting Calculation**

| Scenario | *(Calculate Area "D")* | | | | | *(Calculate Area "G")* | | | | | ***Total Area*** | ***Normal-ized Scenario Weight*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *A* | *B* | *A - B* | *C* | ***D*** | *B* | *E* | *B - E* | *F* | ***G*** | ***D + G*** | |
| | AEP of River Reaching Trigger Elevation | AEP of River Reaching Levee Crest | *width of box* | *height of box* | **Area** *width x height* | AEP of River Reaching Levee Crest | AEP lim - > 0 | *width of box* | *height of box* | **Area** *width x height* | *Prob. of Occur.* | |
| Over-topping | n/a | n/a | n/a | n/a | n/a | 0.0057 | 0.0 | 0.0057 | 1.0 | **0.0057** | 0.0057 | **17%** |
| Dykstra Breach | 0.0029 | 0.0048 | -0.0019 | 0.02 | **0.0000** | 0.0048 | 0.0 | 0.0048 | 1.0 | **0.0048** | 0.0047 | **n/a** |
| Tukwila Breach | 0.5000 | 0.0010 | 0.4990 | 0.02 | **0.0100** | 0.0010 | 0.0 | 0.0010 | 1.0 | **0.0010** | 0.0109 | **33%** |
| Horseshoe Breach* | 0.1000 | 0.0057 | 0.0943 | 0.02 | **0.0019** | 0.0057 | 0.0 | 0.0057 | 1.0 | **0.0057** | 0.0076 | **23%** |
| Meyers Breach | 0.1667 | 0.0057 | 0.1610 | 0.02 | **0.0032** | 0.0057 | 0.0 | 0.0057 | 1.0 | **0.0057** | 0.0089 | **27%** |

*Note: Values rounded to four decimal places.*
** Example shown on Figure 2-1*

**Table 2-4. Scenario Weights**

| Scenario | *Probability of Occurrence* | *Normalized Scenario Weight* |
|---|---|---|
| Levee-Overtopping-then-Breach | 0.0057 | 17% |
| Tukwila / Dykstra Levee Breach | 0.0109 | 33% |
| Horseshoe Bend Levee Breach | 0.0076 | 23% |
| Meyers Golf Levee Breach | 0.0089 | 27% |
| | **TOTAL** | **100%** |

# 3. DAMAGE CATEGORIES

Damage categories are the categories for which an inventory and damage function were developed for input into HEC-FDA. This analysis included damage categories typical to a Corps flood risk evaluation, including the items bulleted below. These damage categories are not intended to encompass all possible flood risks specifically. Rather, they are intended to characterize the magnitude of the primary economic effects using existing information specific to the floodplain and various assumptions which allow the damages to be interpreted more generally.

- Structure and Content Damages
- Damage to Passenger Vehicles and Trucks
- Cleanup Costs, Public Assistance Payments, and Utility Repairs
- Vehicle Traffic and Passenger Rail Delay Costs
- Freight Rail Detour Costs
- Agricultural Crop Losses
- Lost Recreation Value
- King County Regional Economic Impacts

In the following subsections the assessment of each of these categories will be briefly described in order to provide a better context for interpretation of the HEC-FDA modeling discussed in Section 4 and the results that will follow in Section 5.

Evaluation methodologies were carried out in a manner consistent with Corps of Engineers policies and procedures outlined in the Planning Guidance Notebook (Corps of Engineers 2000) and in Engineering Manual 1619, Risk Based Analysis for Flood Damage Reduction Studies (Corps of Engineers 1996). Uncertainty parameters related to the economic inventory were obtained directly from the depth-damage functions used, either Corps of Engineers functions or HAZUS functions. Level of detail in this analysis was at or above that typically included in a SWIF analysis.

## 3.1. STRUCTURE AND CONTENT DAMAGES

The inventory of structures in the floodplain was obtained from King County's HAZUS Level 2 database developed for _the 2013 update to the King County Regional Hazard Mitigation Plan, which reflects 2013 parcel data supplemented with field data collection on a sample of approximately 2,000 structures. Assessment of structure and content damage in HEC-FDA requires that each structure in the floodplain be added to a database which contains structure value, content value, first floor elevation, and structure

type. Structure types correspond to specific depth-to-percent-damage curves developed by the Corps and FEMA.

Consistent with Corps guidance, structure value was estimated as depreciated replacement value in order to estimate the value of the structure which was lost, not the cost to repair the structure. The database included the necessary structure characteristics to estimate replacement value using the 2014 RS Means Cost Methodology (RSMeans 2014) and Marshall & Swift Valuation Service (MVS 2013).

For residential structures, Corps depth-damage curves prevent the need for a separate content valuation. Non-residential content values are determined as a ratio of structure value to content value depending on the structure type. For non-residential structures, FEMA also developed content-to-structure value ratios. First floor elevation by structure type was based on the data already included in the King County Level 2 HAZUS inventory, and average values were applied to structures by structure type.

Uncertainty parameters included for structures and contents include uncertainty about the structure value, content value, first floor adjustment and depth-damage curve. Uncertainty parameters for structures and contents were obtained from Corps guidance for residential structures (Corps of Engineers 2003 and 2000) and from the HAZUS model for non-residential structures. A standard deviation in first floor stage was set at 0.25 feet for all structures to reflect uncertainty in the average values for first floor stage applied by structure type from sample data in the structure database.

As shown in Table 3-1, this analysis estimated a total depreciated replacement value for the inventory of $14.6 billion dollars in structure value. Including content value, this would be expected to about double, as most non-residential structure types have a content value that meets or exceeds its structure value (FEMA 2011). Table 3-2 summarizes the structure inventory by structure type and damage area. The inventory was developed to ensure that all potentially flooded structures would be accounted for. Following completion of the hydraulic modeling, the subset of the inventory which was found to be within the extent of inundation could be identified, as summarized in Table 3-3. As noted in the tables, 5,081 of the originally included 8,908 structures were within the area of inundation.

**Table 3-1. Inventory Depreciated Replacement Value ($1000)**

| Damage Area | Structure Value ($1000) | |
|---|---|---|
| | Non-Residential | Residential |
| Auburn (Upstream Left Bank) | $2,793,316 | $741,484 |
| Tukwila (Downstream Left Bank) | $1,343,870 | $633 |
| Kent/Renton (Right Bank) | $8,184,969 | $560,521 |
| Duwamish (Downstream) | $915,817 | $63,970 |
| **Sub-Total** | $13,237,971 | $1,366,608 |
| **TOTAL** | **$14,604,579** | |

**Table 3-2. Structure Type by Damage Area**

| Damage Area | Structures by Type | | | | |
|---|---|---|---|---|---|
| | Single-Family | Multi-Family | Commercial | Industrial | Other* |
| Auburn (Upstream Left Bank) | 2,966 | 518 | 873 | 74 | 72 |
| Tukwila (Downstream Left Bank) | 10 | 20 | 273 | 13 | 3 |
| Kent/Renton (Right Bank) | 911 | 355 | 1,769 | 178 | 44 |
| Duwamish (Downstream) | 570 | 21 | 196 | 36 | 6 |
| **Sub-Total** | **4,457** | **914** | **3,111** | **301** | **125** |
| **TOTAL** | **8,908** | | | | |
| ** Agricultural, public, and religious structures* | | | | | |

**Table 3-3. Structures within Inundation Extent by Type and by Damage Area**

| Damage Area | Structures by Type | | | | |
|---|---|---|---|---|---|
| | Single-Family | Multi-Family* | Commercial | Industrial | Other** |
| Auburn (Upstream Left Bank) | 1,074 | 268 | 342 | 32 | 30 |
| Tukwila (Downstream Left Bank) | 9 | 11 | 238 | 12 | 2 |
| Kent/Renton (Right Bank) | 761 | 293 | 1,659 | 169 | 39 |
| Duwamish (Downstream) | 75 | 12 | 52 | 3 | 0 |
| **Sub-Total** | **1,919** | **584** | **2,291** | **216** | **71** |
| **TOTAL** | **5,081** | | | | |
| ** Includes all residential structures with two or more units*<br>*** Agricultural, public, and religious structures* | | | | | |

## 3.2. Damage to Passenger Vehicles and Trucks

In the case of the Lower Green, the heavily regulated nature of the floodplain would likely give warning time whereby some residents and business owners would be able to move some vehicles to high ground.

In order to estimate the effects of warning time on passenger vehicles, the number of vehicles assumed to be at risk was developed as a function of the number of residential structures in the floodplain, rather than also included non-residential structures, effectively assuming that vehicles parked at businesses would not be present, but that residents may not be able to relocate their vehicles. A vehicle inventory was created based on the number of residential structures in the floodplain (adjusted for multi-unit structures). Based on the average number of vehicles per household from the 2012 American Community Survey (U.S. Census 2012), and adjusting for new and used car proportions, a vehicle value was created for residential structures. This inventory was entered into HEC-FDA in combination with the Corps generic depth damage function for passenger vehicle damage (Corps of Engineers 2009).

For commercial vehicles, the damage analysis is based on available commercial truck inventory data. The commercial truck inventory was obtained from Census data in FEMA's HAZUS model, which reported the value of trucks by census block. A point inventory was created for census blocks falling inside the study area expected to have trucks present. It was noted that substantial inventory of equipment and specialty vehicles exist in the floodplain which could not be easily moved. For the purposes of modeling, 50% of the inventory value was assumed to be immobile and susceptible to flooding despite warning time. Therefore, while this damage category is based on trucking data, it may be considered a characterization of like-damages that might be expected in the area due to the high number of

commercial and industrial facilities in the floodplain. The FEMA depth damage function for commercial trucks from HAZUS was entered into HEC-FDA. For both the passenger and commercial vehicle inventory, uncertainty is captured via inclusion of a 15% standard deviation on vehicle value.

## 3.3. Cleanup Costs, Public Assistance Payments, and Utility Repairs

Post-flood response costs are estimated in this analysis based on application of cleanup costs to inundated structures, estimates of FEMA public assistance payments based on the number of structures flooded, and generalized estimates of utility damage. Collectively, these three damages provide an estimate of damages typically associated with post-flood cleanup and response.

Cleanup costs occur in the aftermath of flood inundation where debris, sediment, and moisture must be dealt with before residences and businesses can return to normal operation. Cleanup costs were applied on a dollar-per-first-floor-square-foot basis to residential and commercial structures. Review of inventory resulted in exclusion of cleanup costs for some industrial and warehouse structure types, as their structure types typically do not require a specialized cleaning service. A cleanup cost per square foot of $4.50 was applied to all relevant structure types based on the cost estimated for the 2012 King County 180th Street to 200th Street Levee Setback Study (King County 2012).

FEMA public assistance payments can take the form of Housing Assistance, Other Needs Assistance, or Public Assistance. Housing Assistance includes things like temporary disaster housing grants, rental reimbursement, and temporary repair assistance. Other Needs Assistance covers disaster related medical, dental, funeral, transportation or other expenses not covered by insurance. Finally, Public Assistance covers the repair, replacement, or restoration of disaster-damaged public owned facilities or facilities of certain Private Non-Profits. A recent Corps of Engineers analysis of FEMA Disaster Expenditures across the nation resulted in an estimate of combined public assistance payments of $9,690 dollars per flooded residential structure (Corps of Engineers 2009). This value was used to setup a depth damage function for residential structures which was triggered at 1 foot of inundation.

Utility damages were applied generally based on estimated utility network infrastructure value in the FEMA HAZUS model for potable, wastewater, electric, and communication utilizes. FEMA inventory data falling inside the study area was added to the HEC-FDA inventory along with the corresponding FEMA utility depth damage function. Because HAZUS includes utility information at a coarse level, this damage category should be considered an estimate of system-wide utility disruption effects rather than specifically-located utility damages.

## 3.4. Vehicle Traffic and Passenger Rail Delay Costs

When inundation causes road and rail closures, the dollar value of time delays encountered may be counted as a damage. In this case, estimates were developed for the delays associated with vehicle traffic and passenger rail traffic rerouting. This analysis relies on estimates of time delays based only on increased mileage and does not account for the potential increases in detour travel time due to congestion.

For vehicle traffic, WSDOT average daily traffic counts were pulled for SR- 167, SR- 516, and SR- 181 (West Valley Highway). For each highway, a detour was estimated which allowed traffic to circumvent the floodplain, adding between five and ten minutes per trip based on the additional miles necessary for

the detour. This time delay was converted to a dollar value per trip based on Corps guidance (Corps of Engineers 2000a). A frequency damage function was estimated based on the number of days that delays would be expected for increasing flood severity. For the largest flood, a maximum of 14 days of detour was assumed, which is intended to account for days of inundation as well as any required repairs prior to reopening. For the most frequent damaging flood, three days of detour was assumed. This frequency-damage function was converted to stage-damage function for incorporation into HEC-FDA.

While specific repair costs to transportation infrastructure is often difficult to predict, use of highway traffic volumes moving through the study area allows this damage category to provide a characterization of the level of impact that temporary road closures throughout the system can induce. While delays are used as a proxy, a component of traffic-related damages would be expected to be cleanup and repair.

A similar analysis was conducted for passenger rail delays. It was assumed that for floods where the rail line was inundated, passenger rail users would instead bus or drive, effectively making them subject to the same ten minute delays as estimated for the vehicle traffic. The same Corps methodology was applied and the total rail trips was converted to a frequency damage function based on the number of days that delays would be expected for increasing flood severity. This frequency-damage function was converted to a stage-damage function for incorporation into HEC-FDA.

## 3.5. Freight Rail Detour Costs

BNSF Railroad operates a mainline through the study area. BNSF provided data on typical freight train traffic through the area, which includes approximately 35 trains per day, 365 days per year (BNSF 2014). Using the national average freight operating cost per ton mile and average tons per train, the cost per train per mile was estimated (AAR 2013). Per discussion with BNSF, trains would be rerouted around the study area as needed via Steven's Pass, Stampede Pass, and the Columbia River Gorge, depending on destination. It was estimated that half of the daily traffic could be rerouted with a minimal detour of 60 miles. However, it was estimated that the other half of daily trains would require a more substantial 268 additional miles. Based on this additional mileage, it was estimated that freight detours would result in approximately $544,000 dollars of additional operating cost per day.

Next, a frequency damage function was estimated based on the number of days that detours would be expected for increasing flood severity. It was assumed that the least damaging flood would require only one day of detours, perhaps from precautionary closure, while the largest flood may require up to 14 days of detour to account for both days of inundation and any subsequent inspection and repair undertaken by BNSF. This frequency-damage function was converted to a stage-damage function for incorporation into HEC-FDA.

## 3.6. Agricultural Crop Losses

The Lower Green Agricultural Production District is located in the Auburn (upstream left bank) damage area. Inundation of active cropland can result in lost crops, and therefore lost agricultural production value. The estimated value of lost crops was based on the potential crop revenue per acre (provided by the Agricultural Production District) and adjustment for production cost expenditure schedule. Based on the provided acreage of market crops and nursery crops, and an estimated value of $10,000 per market crop acre and $20,000 for nursery crop acre, potential revenue for a single harvest was estimated at $10.2 million. Based on published crop cost and return studies for various market crops, it was estimated that about 50% of production cost is tied to harvest. Therefore, 50% of the $10.2 million was

estimated at the maximum lost crop value in the event of a flood. Next, a frequency-damage function was estimated based on review of the FLO2D flood model results. A percent crop loss was estimated ranging from 10% at the least damaging flood to 100% at the largest flood. This frequency-damage function was converted to a stage-damage function for incorporation into HEC-FDA. Other damages related to the agricultural industry are characterized implicitly in other damage categories such as structure and content damages and vehicle damages. However there may be additional agricultural costs not specifically accounted for in this analysis, such as any specialized cleanup or restoration costs that would be required to bring agricultural land back to plantable condition.

## 3.7. Lost Recreation Value

Recreation impacts due to flooding are based upon assumed reduction in the quantity of recreation during and immediately following a flood event. In order to estimate recreation effects, the Corps of Engineers Unit Day Value methodology was employed. This methodology allows for estimating recreation value per visit by completing a scoring rubric for the recreation resource. The score is converted to a dollar value based on annual published guidance (Corps of Engineers 2013), and this value is multiplied by an estimate of visitation to yield total recreation value.

Visitation was estimated based on length of trail in the damage areas. Using urban trail guidelines for trail capacity (NRPA 1983), and adjusting for seasonal and weekend/weekday use, daily visits to recreation resources along the river in the damage areas was estimated at about 2,500. This estimate was corroborated by local parking lot count and bicycle/pedestrian count data for the Green River Trail, which results in an estimate of 2,164 visits per day. It was assumed that 2,500 visits was appropriate based on additional users of parks along the river not captured by parking lots counts. The existing condition recreation resources along the river were scored and resulted in a value of $7.49 per visit. Next, a frequency damage function was estimated based on the number of days the recreation resources would be inaccessible or degraded for increasing flood severity. It was assumed that the least damaging flood would result in one day of lost recreation value, while the largest flood might result in up to 14 days of lost recreation value. This frequency-damage function was converted to a stage-damage function for incorporation into HEC-FDA.

## 3.8. King County Regional Economic Impacts

Typically Corps of Engineers analyses include as project benefits only national economic development (NED) effects, as the planning context for the Corps of Engineers is to consider net effects at the national level. As such, regional incidence of effect such as income transfers and employment effects are not counted in a typical NED benefit-cost analysis, but are instead considered separately in the regional economic development (RED) account (Corps of Engineers 2000). While the SWIF process does not require specific NED and RED analyses, it is useful to characterize regional economic effects separately.

For the SWIF process, regional economic effects were measured based on the King County economy, as defined in the IMPLAN model methodology, described below.

### 3.8.1. Input-Output Methodology

RED impacts are typically quantified using regional economic input-output models. In this analysis, the IMPLAN model was used. IMPLAN measures the flow of commodities and services among industries,

institutions, and final consumers within an economy, which can be defined at different geographic levels. In this case the regional economy was defined as King County.

The IMPLAN model is designed to capture all monetary market transactions in an economy, accounting for inter-industry linkages and availability of regionally-produced goods and services in order to predict the economic impacts of a change in one or several economic activities on an entire economy. These linkages are captured via multipliers which have been developed based on continual review and update of industry data.

For the Lower Green flood risk assessment, the change in economic activity used as input to IMPLAN is an estimated reduction in employment due to temporary business closures. This reduction in employment is translated to reduction in economic output by industry, resulting in direct, indirect and induced effects in terms of regional output (total sales) and employment (jobs). The damages to business structures and inventories was accounted for in assessment of damages to structures and contents described in Section 3.1.

Direct economic effects refer to the response of a given industry (i.e., changes in output, income, and employment) based on final demand for that industry. In this case, direct effects are adverse because they represent a loss of employment. Employment loss is controlled by days of business closure following a flood, which directly results in reduced output for an industry. As an example, consider a week of closure at a manufacturing facility in the floodplain. This closure would result in a week of reduced output by the industry and a week of reduced income for its employees.

Indirect effects refer to changes in output, income, and employment resulting from the iterations of industries purchasing from other industries caused by the direct economic effects. In the example, reduced output by the manufacturing facility would reduce demand, and therefore output, of their suppliers, which might include area sheet metal or welding material manufacturers, therefore also reducing income of the employees of these suppliers by some fraction of the original five days of closure.

Finally, induced economic effects refer to changes in output, income, and employment caused by the changes in expenditure of household income generated by direct and indirect economic effects. In the example using a manufacturing facility, the employees of the manufacturer, as well as the employees of the sheet metal and welding equipment suppliers, would be expected to reduce expenditures in other sectors of the economy (such as restaurants or entertainment) by some fraction of their reduction in income based on the original week of closure due to flooding. These inter-industry effects are carried through the economy.

While these regional economic impacts provide valuable information at the local level, it is important to note that once the scope of the regional analysis is expanded, the results may differ substantially. If for example, a flood on the Lower Green resulted in a week of closure at a manufacturing business, it may also result in increased production at a competitor's Pierce County manufacturing facility, possibly offsetting some portion of the estimated effects on income and employment when viewed through a wider lens. However, the extent to which inter-regional transfers occur is a function of regional or national specialization in the study area. For certain specialized industries, such as aerospace engineering and manufacturing, there may not be an opportunity for demand to be met by another region.

### 3.8.2. SWIF Regional Economic Analysis Implementation

The goal of the SWIF regional economic analysis was to characterize the regional economic impacts of flooding on the Lower Green over a range of flood flows. In order to do so, three system-wide IMPLAN models were developed based on modeled floodplain depth grids in FLO-2D. These three IMPLAN models roughly correspond to low, medium, and high impact levels based on the area of the floodplain inundated by the 11,900 cfs (low C.L., 10% AEP), 15,100cfs (high C.L., 1% AEP) and 26,800 cfs (high C.L., 0.2% AEP) flood flows, respectively. The resulting regional economic impacts from the three model runs were then plotted in order to form a frequency-impact function. Further detail on the inputs to the IMPLAN model are described below.

Inputs to IMPLAN were estimated employment effects by industry in the floodplain. IMPLAN is an event-based annual model, meaning that the employment impacts used as an input are required to be calculated in terms of full-time equivalent (FTE) jobs, or the proportion of one full time work year.

King County provided a database of floodplain businesses in geospatial format which included industry code classifications for each business as well as an estimate of number of employees for each business. Using this inventory and the hydraulic modeling results, the number of employees affected by industry was estimated. Industries were grouped into five categories listed below for tabulating model inputs.

- Mining and Construction
- Manufacturing
- Transportation, Communications & Public Utilities, and Public Administration
- Wholesale Trade and Retail Trade, and
- Services

Conversion of affected employees to FTE employment effects required estimation of the length of time businesses would be closed during and following the flood, referred to as downtime. Downtime estimates were defined for six levels of inundation, as shown in Table 3-4. These downtime estimates were based on consideration of the default downtime values in HAZUS (FEMA 2011) as well as judgment regarding the types of activities that would be required by businesses prior to re-opening at different levels of inundation. It was estimated that below a foot of water, businesses may not need to hire third-party professional cleaners and would be able to utilize existing employees in the cleanup effort, which would not constitute a reduction in employment. Between and one foot and two feet of water, cleanup requirements would likely intensify, requiring specialized cleaners and a closure period sufficient to carry out the cleaning and ensure that the structure is in normal operating condition. Above two feet of water, depending on the structure, more substantial damages are likely to occur, such as damage to electrical work, which would require repair prior to reopening. As structure damage and repair requirements increase, regulatory, permitting, and inspection requirements may further extend downtime, as shown in the three-to-five feet and 5 feet or more depth ranges. It is important to note that this analysis does not assume any business/workplace relocations.

It is assumed that all businesses will remain in place, repair and reopen according to the downtimes shown in Table 3-4. This is especially important for larger floods, where substantial building damage may induce companies to relocate outside of the floodplain, possibly reducing their downtime, but representing a permanent loss to the Lower Green economic area. However, determining whether specific businesses would relocate is not within the scope of this impact analysis, and so effects are modeled based on downtime, assuming no relocations.

**Table 3-4. Business Downtime by Depth Range**

| Depth Range | Estimated Downtime (workdays) |
|---|---|
| Under 0.5 feet | 1 day |
| 0.5 to 1 foot | 2 days |
| 1 to 2 feet | 2 weeks |
| 2 to 3 feet | 2 months |
| 3 to 5 feet | 6 months |
| 5 or more feet | 1 year |

In order to determine the proportion of affected businesses in each of the six downtime ranges, preliminary HEC-FDA model runs were used to determine the percent of the structure inventory which fell into each depth range. These percentages were assigned to the three IMPLAN model runs as shown in Table 3-5.

**Table 3-5. Estimated Percent of Businesses in each Depth Range**

| Depth Range | IMPLAN Model 1<br>11,900 cfs<br>*(low C.L., 10% AEP)* | IMPLAN Model 2<br>15,100 cfs<br>*(high C.L., 1% AEP)* | IMPLAN Model 3<br>26,800 cfs<br>*(high C.L., 0.2% AEP)* |
|---|---|---|---|
| Under 0.5 feet | 36% | 49% | 9% |
| 0.5 to 1 foot | 18% | 24% | 9% |
| 1 to 2 feet | 46% | 18% | 24% |
| 2 to 3 feet | 0% | 7% | 16% |
| 3 to 5 feet | 0% | 3% | 19% |
| 5 or more feet | 0% | 0% | 23% |
| *Values may not add up due to rounding* | | | |

Finally, having estimated the number of employees by industry, and the length of time the employees would be affected, FTE effects were calculated for each model run by industry. Table 3-6 summarizes the direct FTE effects of flooding by generalized industry groups for each model.

**Table 3-6. Adverse Employment Effects by Industry Group (Full Time Equivalent Jobs)**

| Description | IMPLAN Model 1<br>11,900 cfs<br>*(low C.L., 10% AEP)* | IMPLAN Model 2<br>15,100 cfs<br>*(high C.L., 1% AEP)* | IMPLAN Model 3<br>26,800 cfs<br>*(high C.L., 0.2% AEP)* |
|---|---|---|---|
| Mining and Construction | 7 | 64 | 1,788 |
| Manufacturing | 7 | 244 | 5,014 |
| Transportation, Communications & Public Utilities, and Public Administration | 11 | 116 | 2,896 |
| Wholesale Trade and Retail Trade | 65 | 415 | 10,231 |
| Services | 41 | 330 | 7,505 |
| **TOTAL** | **130** | **1,169** | **27,435** |
| *Values may not add up due to rounding* | | | |

The FTE employment effects serve as the inputs to the three IMPLAN models. IMPLAN was then run to estimate the total direct, indirect, and induced regional economic effects of these temporary employment reductions on the King County economy for a single year. The following sections discuss use of the results to develop a general frequency-damage function for use in HEC-FDA in order to generate expected annual regional economic impacts.

### 3.8.3. IMPLAN Results and Frequency-Damage Conversion

As noted above, IMPLAN results provided point estimates of effects. Table 3-7 summarizes the adverse employment and total output effects for the three model runs.

**Table 3-7. IMPLAN Model Outputs**

| Impact Type | IMPLAN Model 1<br>11,900 cfs<br>*(low C.L., 10% AEP)* | | IMPLAN Model 2<br>15,100 cfs<br>*(high C.L., 1% AEP)* | | IMPLAN Model 3<br>26,800 cfs<br>*(high C.L., 0.2% AEP)* | |
|---|---|---|---|---|---|---|
| | **FTEs** | **Total Output ($)** | **FTEs** | **Total Output ($)** | **FTEs** | **Total Output ($)** |
| Direct | 130 | $19,651,000 | 1,169 | $191,268,000 | 27,435 | $4,433,344,000 |
| Indirect | 41 | $7,191,000 | 393 | $69,934,000 | 9,138 | $1,619,001,000 |
| Induced | 53 | $8,158,000 | 481 | $74,785,000 | 11,257 | $1,748,962,000 |
| **TOTAL** | **224** | **$35,000,000** | **2,044** | **$335,987,000** | **47,830** | **$7,801,307,000** |

The table shows that for the least damaging IMPLAN run (IMPLAN Model 1), business closures in the floodplain equivalent to 130 FTEs would result in 41 additional FTEs being lost in the County. The combined effect of the 130 FTE and 41 FTE loss would result in 53 FTEs being lost due to a reduction in induced spending in the economy. Note again that FTEs are *equivalent* to years' worth of full time employment, but is comprised in this case by a number of employees losing a partial year of employment. These employment effects increase substantially for the larger floods.

Similarly, the least damaging flood results in $19.6 million in reduced output (total business sales/revenue) for direct effects, which in turn results in $7.1 million in reduced output for indirect effects, and $8.2 million in induced effects, for a total of $35 million dollars of reduced economic output in the King County economy. These effects increase substantially for the larger floods in proportion to the increase in downtime estimated for inundated businesses. The highest damaging flood results in effects in the billions of dollars, reflecting that downtimes for a substantial number of businesses were modeled at one year, as shown in Tables 3-4 and 3-5 (note this analysis assumes no workplace transfers).

In order to utilize these results in HEC-FDA by damage area, the effects were proportionally allocated to damage areas based on the proportion of affected businesses in each damage area for the largest IMPLAN model run. This adjustment, which is not industry-specific, allows for a damage function to be entered for each damage area in HEC-FDA. Approximately 66% of effects were associated with the Kent/Renton damage area (right bank), 18% were associated with the Tukwila damage area (downstream left bank), 12% with the Auburn damage area (upstream left bank), and 5% with the Duwamish damage area (downstream). Based on the hydraulic parameters of each damage area model, frequency-damage functions and stage-damage functions were created for incorporation into HEC-FDA.

# 4. HEC-FDA Implementation

The HEC-FDA software was developed by the Corps of Engineers and provides the capability to perform an integrated hydrologic engineering and economic analysis to assist with the evaluation of flood risk. The software requires study-specific hydrologic, geotechnical, and economic data to compute expected annual damage (EAD). EAD is the damage that can be expected in any year of the period of analysis,

where damage corresponding to each magnitude of flooding is weighted by the percent chance of each being exceeded (damage caused by rare events is thus weighted less). The sum of the weighted damage represents the EAD. Stated alternatively, system-wide EAD is equivalent to the area under the system-wide frequency-damage curve.

The software provides for input of flood depth grids, an exceedance-discharge function with uncertainty, a stage-discharge function with uncertainty, and a geotechnical-fragility function. The software also requires the economic inventory to be linked to depth-damage or stage-damage functions which may include uncertainty. The software then processes the combination of hydraulic, hydrologic, geotechnical, and economic functions in order to estimate EAD with uncertainty. The following subsections will describe implementation of HEC-FDA for the SWIF process.

## 4.1. Scenario and Damage Area Models

The nature of damage calculations in HEC-FDA using FLO-2D data allows for only one levee condition per damage area model. Therefore, because the team defined four damage areas and four existing condition scenarios, sixteen HEC-FDA models were required in order to account for each scenario-damage area combination. Within a scenario, four damage area models were run to complete the system-wide EAD for that scenario. Each damage area modeled relies on the results of the hydraulic model for the six flood flow events (described further in Section 4.1.1). As was described in Section 2.5, the four scenario EADs were then weighted in order to generate a single system-wide EAD. Table 4-1 summarizes the sixteen models used to capture the four existing condition scenarios defined in Section 2.2.

**Table 4-1. Suite of HEC-FDA Models**

| Model | Scenario | Damage Area | Fragility-Based Levee Breach |
|---|---|---|---|
| 1 | Levee-Overtopping-then-Breach | Upstream Left Bank (Auburn) | No |
| 2 | | Downstream Left Bank (Tukwila) | No |
| 3 | | Right Bank (Kent/Renton) | No |
| 4 | | Downstream (Duwamish) | No |
| 5 | Tukwila / Dykstra Levee Breach | Upstream Left Bank (Auburn) | Yes |
| 6 | | Downstream Left Bank (Tukwila) | Yes |
| 7 | | Right Bank (Kent/Renton) | No |
| 8 | | Downstream (Duwamish) | No |
| 9 | Horseshoe Bend Levee Breach | Upstream Left Bank (Auburn) | No |
| 10 | | Downstream Left Bank (Tukwila) | No |
| 11 | | Right Bank (Kent/Renton) | Yes |
| 12 | | Downstream (Duwamish) | No |
| 13 | Meyers Golf Levee Breach | Upstream Left Bank (Auburn) | No |
| 14 | | Downstream Left Bank (Tukwila) | No |
| 15 | | Right Bank (Kent/Renton) | Yes |
| 16 | | Downstream (Duwamish) | No |

### 4.1.1. Hydraulic, Hydrologic, and Geotechnical Inputs

#### 4.1.1.1. Eight-Event Water Surface Profile

HEC-FDA requires for each model that a set of depth-grid profiles be added which correspond to the depth of water in the floodplain at each of eight increasing flood events. As described in Section 3.7 of the Hydraulics Technical Memorandum, grids were provided for six profiles for each model. The seventh and eighth flows were added manually. A minimum flow of 3,500 cfs (median, 99.99% AEP) was added which was assumed to result in no flooding throughout the system. The last flow was interpolated between the 9,900 cfs (high C.L., 50% AEP) flood and the 11,900 cfs (low C.L., 10% AEP) flood provided by the hydraulics team at approximately 11,000 cfs (median, 20% AEP). For each completed set of eight profiles, the hydraulics team provided the required stage-discharge curve at the damage area index locations, as described in Section 3.7 of the Hydraulics Technical Memorandum.

#### 4.1.1.2. Exceedance Discharge with Uncertainty

As discussed in Section 2 of the Hydraulics Technical Memorandum, the exceedance-discharge function for the Lower Green is heavily regulated by HHD. In order to reflect the regulation in the uncertainty associated with the exceedance-discharge function in HEC-FDA, the software's Transform-Flow function was used with a triangular distribution to relate regulated flows at the Auburn Gage to unregulated inputs to HHD based on the Corps of Engineers design hydrographs (Corps of Engineers 2012).

#### 4.1.1.3. Stage-Discharge with Uncertainty

The stage-discharge curve varies between the HEC-FDA model as a function of the index location chosen for a given model, which was based on a representative river cross-section for the damage area taking into account potential expected levee breaches. Estimation of stage-discharge uncertainty in the hydraulic results is discussed in Section 3.7 of the Hydraulics Technical Memorandum. Based on this input, uncertainty in the stage-discharge relationship was set using a normal distribution with a constant standard deviation of 0.77 feet.

#### 4.1.1.4. Levee Features

HEC-FDA allows for inclusion of a fragility curve to control the occurrence of damage. For those models marked as including a fragility curve in Table 4-1, the fragility curves presented in the Geotechnical Technical Memorandum were incorporated into the model. These include the fragility curve for Dykstra, Tukwila, Horseshoe Bend, and Meyers Golf levees. For models containing a fragility curve, all damages are dependent upon a levee failure occurring. While the Tukwila and Dykstra levees are included in the same scenario, both of their levee fragility curves are reflected in HEC-FDA because they are accounted for in different damage areas (and therefore by different HEC-FDA models).

### 4.1.2. Economic Inputs

#### 4.1.2.1. Economic Inventory

For damage categories using depth-damage functions, an inventory must be entered into HEC-FDA. Each inventory entry is assigned a floodplain grid ID which corresponds to a grid in the FLO-2D water surface profiles. The depths at a grid control flooding of the inventory associated with that grid. Next, each inventory item is assigned a first floor elevation, a structure value and a content value, and a structure type. The structure type assignment then corresponds to which of the depth-damage functions will be used to calculated flood damages for that inventory item. Uncertainty parameters are defined for

structures as well. These include uncertainty in structure value and in first floor height above ground. Uncertainty in structure value is sometimes provided in published depth-damage functions. When not provided, a standard deviation of 15% was used. Uncertainty in the height above ground adjustment was set at 0.25 feet standard deviation.

#### 4.1.2.2. Depth-Damage Functions

As discussed in Section 3, Structure and Content Damages, Damage to Passenger Vehicles and Trucks, and Cleanup Costs, Public Assistance Payments, and Utility Repairs all rely on established depth-to-percent-damage functions which relate depth at a given point in the floodplain with percent of damage applied to item being considered at that point. These functions are published by the Corps of Engineers as well as by FEMA through the HAZUS model. The uncertainty parameters of each depth-damage function were carried forward. Typically, Corps of Engineers functions for residential structures and contents used a standard deviation of percent damage, while commercial/industrial structure depth damage curves from FEMA used a triangular distribution.

#### 4.1.2.3. Stage-Damage Functions

The remaining damage categories were included in HEC-FDA using stage-to-dollar-damage functions. For these categories, no inventory is entered into HEC-FDA; use of a dollar-damage function skips the inventory step. For each damage category, the frequency-damage functions developed in Section 3 had to be converted to stage-damage functions. Because stage is relative to the index location of each HEC-FDA model, multiple stage-damage functions had to be created for each damage category in order to correctly relate stage at the index to frequency of damage occurrence across all the damage areas. This frequency-stage relationship was obtained for each model run from an output of the HEC-FDA model itself, which creates a frequency-stage report based on the exceedance-discharge and stage-discharge relationships with uncertainty that have been entered.

## 4.2. Results

After populating all necessary components of the models as outlined in Section 4.1, each was run to calculate EAD. Amortization of EAD to estimate present value (PV) relies on the FY14 Federal Interest Rate for Federal Water Resources Project Studies of 3.5% (Corps of Engineers 2013a) and a 50-year period of analysis.

The manner by which HEC-FDA estimates damage based on hydraulic and economic inputs is summarized in Figure 4-1, below. As shown in the top left quadrant, hydraulic inputs are used to define the flow-exceedance relationship with uncertainty. The top right quadrant illustrates a rating curve which is defined by hydraulic modeling, and allows exceedance-flow and stage-flow to be related. As shown in the lower left quadrant, HEC-FDA combines hydraulic and economic inputs to define the stage-damage relationship. Finally, the lower right quadrant shows that these linked hydraulic and economic relationships allow computation of an exceedance-damage function. Integration of this function results in the EAD over the period of analysis.

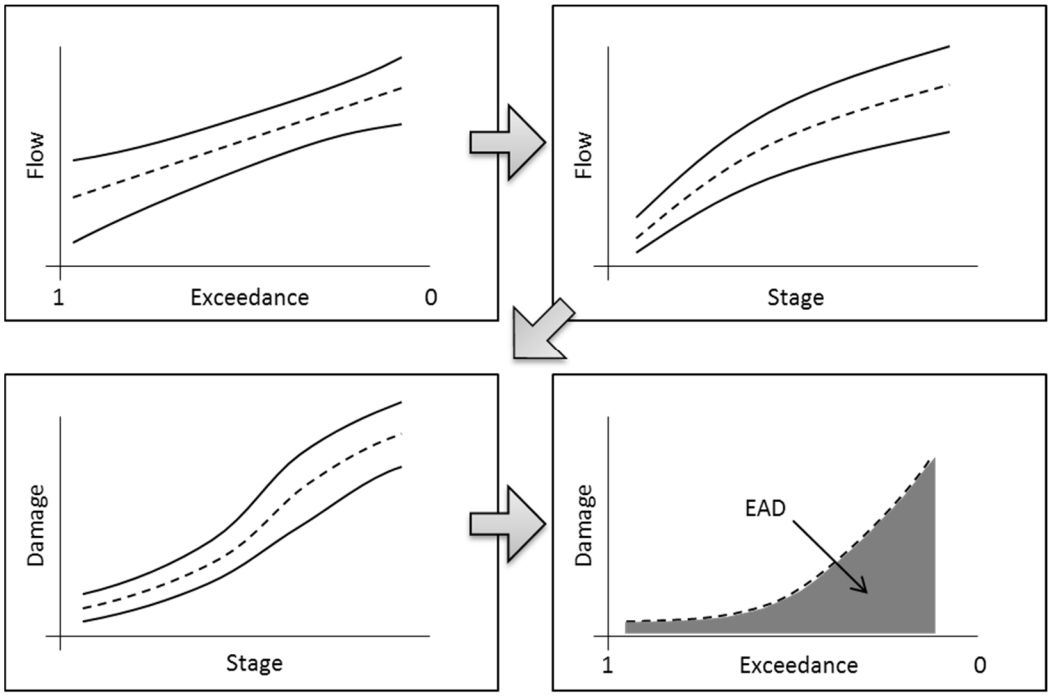


**Figure 4-1. EAD Computation Process in HEC-FDA**

In order to present results in a manner consistent with a typical Corps of Engineers analysis, NED damage categories and the IMPLAN-based RED impacts are shown on different subtotal lines in the tables that follow. From the Federal perspective, reductions in RED account damages by a project could not be counted as a benefit of the project for the purposes of calculating the project's benefit-to-cost ratio.

The following text will summarize the results of the models by scenarios and by damage area using the tables described below:

- Table 4-2: Summary of EAD and PV by system-wide existing condition scenario
- Table 4-3 to 4-6: Detailed Tables, EAD by Scenario, Damage Area, and Damage Category. Note that gray-filled cells in these tables indicate that no damage tabulation occurred there, but does not indicate zero risk. For some damage categories, damages are tabulated at just one or two damage areas but are still intended to characterize risk system-wide.

As shown in Table 4-2, the HEC-FDA modeling for the four existing condition scenarios resulted in EAD for the NED categories of between $17.0 and $22.5 million dollars. The EAD for RED damages based on IMPLAN modeling varies from $25.8 to $32 million dollars. The following subsections summarize observations based on comparison of the results by scenario.

### 4.2.1. Overtopping versus Breach Results

Table 4-2 shows that the EAD for the levee-overtopping-then-breach scenario is similar in scale to the EAD for the scenarios with breach below the levee crest. Based on the geotechnical and hydraulic parameters in this analysis, damages occur from overtopping at a frequency similar to the frequency at which a breach is likely to be triggered based on the fragility curves.

### 4.2.2. Auburn Damage Area (Upstream Left Bank) Considerations

Comparison of results for the Auburn damage area in the levee-overtopping-then-breach scenario (Table 4-3) and Tukwila/Dykstra levee breach (Table 4-4) scenarios show that damages in the upstream left bank area seem greater in the levee-overtopping-then-breach scenario than in the Tukwila/Dykstra levee breach scenario. This is attributable in part to the modeling methodology, where the levee-overtopping-then-breach scenario does not employ a fragility curve and reflects all water entering the floodplain in areas without levees. In contrast, in the Tukwila/Dykstra levee breach scenario, the Dykstra levee must breach based on the fragility curve for damages to occur anywhere in the damage area. As modeled, damages in this area are substantially influenced by the portions of the upstream left bank without levees. Sensitivity analysis was performed which indicates that damages associated with a breach at Dykstra result in about a 10% increase in the EAD versus the levee-overtopping-then-breach scenario model run.

### 4.2.3. Tukwila Damage Area (Downstream Left Bank) Considerations

The Tukwila damage area and Tukwila levee performed generally as expected. In the levee-overtopping-then-breach scenario, damages in this area are relatively low, as few flood flows are sufficient to overtop the levee (Table 4-3). The addition of Tukwila levee fragility curve and consideration of breach in Table 4-4 results in a substantial increase in damages. This is consistent with initial geotechnical and hydraulic work that indicated that the Tukwila levee breach trigger may occur at a more frequent flow than the other levee breach locations modeled in the analysis. This relationship is also reflected in the relative weighting of the system-wide existing condition scenarios discussed in Section 2.5.

### 4.2.4. Kent/Renton Damage Area (Right Bank) Considerations

The Kent/Renton damage area (right bank) is the largest area modeled and damages in this area were modeled via the levee-overtopping-then-breach scenario and two levee breach locations via the Horseshoe levee breach and the Meyers levee breach scenarios. The results in Table 4-3 through Table 4-6 indicate that all four of the scenarios had damages similar in scale for this damage area.

- The Tukwila/Dykstra levee breach scenario results in the lowest EAD for the right bank damage area. This indicates that the presence of a breach in the upstream left bank or downstream left bank areas can result in reduced depths in the right bank, though modeled damages remain substantial.
- The comparison of the Horseshoe levee breach and Meyers levee breach scenarios for the right bank damage area shows that the risk of breach at the Meyers levee results in a larger EAD than with a breach at Horseshoe. Review of the inundation maps developed for the SWIF appear consistent with this result as they indicate that a breach in the vicinity of the Meyers Golf levee is likely to result in a larger floodplain inundation area than a breach near Horseshoe Bend on the right bank.
- The levee-overtopping-then-breach scenario results in an EAD for the right bank damage area that falls between the EAD estimate for the Horseshoe levee breach and the Meyers levee breach scenarios. This result in the model is discussed below:
    - Both the Meyers and Horseshoe levee fragility curves exhibit low risk of geotechnical failure until near the top of levee, and both levees are likely to be overtopped by the 15,100 cfs (high C.L., 1% AEP) flood.

- In the development of the levee-overtopping-then-breach scenario (as described in Section 3.7 of the Hydraulics Technical Memorandum) the right bank damage area had a composite grid applied at the 15,100 cfs (high C.L., 1% AEP) flood.
- Therefore, the levee-overtopping-then-breach scenario reflects a similar risk of water entering the floodplain at the 15,100 cfs (high C.L., 1% AEP) flood as the Horseshoe and Meyers scenarios. Further, sensitivity analysis showed for the 15,100 cfs (high C.L., 1% AEP) flood that because of the grid composite approach, the levee-overtopping-then-breach scenario included more grids with inundation than either the Horseshoe levee breach or Meyers levee breach floodplains alone.

### 4.2.5. Duwamish Damage Area (Downstream) Considerations

The Duwamish Damage Area does not contain any PL 84-99 levee systems. No levee failure analysis was conducted for the Duwamish damage area. Table 4-2 reflects damages in the Duwamish damage area. The results in Table 4-3 through Table 4-6 reflect only small changes in the amount of water expected to overtop the levees across the four existing condition scenarios. As modeled, the effects in the Duwamish damage area are consistent across the scenarios.

### 4.2.6. Damage Summary Tables

The tables referenced in the above sections are presented below. Following the tables, Section 5 documents the estimation of the single weighted system-wide EAD.

**Table 4-2. Expected Annual and Present Value Damage by Scenario**

| Scenarios | System-Wide Total | | |
|---|---|---|---|
| | $ EAD | $ PV | % |
| **Levee-Overtopping-then-Breach** | | | |
| NED Damage Categories Total | $17,478,000 | $409,957,000 | 39% |
| RED King County Regional Output Effect | $27,175,000 | $637,406,000 | 61% |
| **Total** | **$44,653,000** | **$1,047,363,000** | **100%** |
| **Tukwila / Dykstra Levee Breach** | | | |
| NED Damage Categories Total | $22,534,000 | $528,549,000 | 47% |
| RED King County Regional Output Effect | $25,897,000 | $607,430,000 | 53% |
| **Total** | **$48,431,000** | **$1,135,979,000** | **100%** |
| **Horseshoe Bend Levee Breach** | | | |
| NED Damage Categories Total | $16,998,000 | $398,699,000 | 40% |
| RED King County Regional Output Effect | $25,817,000 | $605,554,000 | 60% |
| **Total** | **$42,815,000** | **$1,004,253,000** | **100%** |
| **Meyers Golf Levee Breach** | | | |
| NED Damage Categories Total | $17,974,000 | $421,591,000 | 36% |
| RED King County Regional Output Effect | $32,008,000 | $750,767,000 | 64% |
| **Total** | **$49,982,000** | **$1,172,358,000** | **100%** |

**Table 4-3. Levee-Overtopping-then-Breach Scenario, EAD by Damage Area and Category**

| | EAD by Damage Area and Damage Category ($) | | | | |
|---|---|---|---|---|---|
| **Damage Category** | Auburn (Upstream Left Bank) | Tukwila (Downstream Left Bank) | Kent/Renton (Right Bank) | Duwamish (Downstream) | **TOTAL** |
| Agricultural Crop Losses | $145,000 (4.2%) | | | | **$145,000 (0.8%)** |
| Damage to Passenger Vehicles and Trucks | $312,000 (9.0%) | $0,000 (0.0%) | $182,000 (1.7%) | $139,000 (4.1%) | **$633,000 (3.6%)** |
| Residential Structure & Contents Damages | $416,000 (12.1%) | $0,000 (0.0%) | $161,000 (1.5%) | $969,000 (28.8%) | **$1,546,000 (8.8%)** |
| Non-Residential Structure & Contents Damages | $2,042,000 (59.2%) | $234,000 (97.5%) | $9,956,000 (95.5%) | $2,039,000 (60.7%) | **$14,271,000 (81.7%)** |
| Cleanup Costs, Public Assistance Payments, and Utility Repairs | $102,000 (3.0%) | $6,000 (2.5%) | $89,000 (0.9%) | $211,000 (6.3%) | **$408,000 (2.3%)** |
| Freight Rail Detour Costs | $165,000 (4.8%) | | | | **$165,000 (0.9%)** |
| Vehicle Traffic and Passenger Rail Delay Costs | $266,000 (7.7%) | | $41,000 (0.4%) | | **$307,000 (1.8%)** |
| Lost Recreation Value | $1,000 (0.0%) | $0,000 (0.0%) | $1,000 (0.0%) | $1,000 (0.0%) | **$3,000 (0.0%)** |
| **Sub-Total** | **$3,449,000 (100%)** | **$240,000 (100%)** | **$10,430,000 (100%)** | **$3,359,000 (100%)** | **$17,478,000 (100%)** |
| NED Damage Categories Total | $3,449,000 (36.6%) | $240,000 (22.9%) | $10,430,000 (38.6%) | $3,359,000 (46.8%) | **$17,478,000 (39.1%)** |
| RED King County Regional Output Effect | $5,970,000 (63.4%) | $810,000 (77.1%) | $16,580,000 (61.4%) | $3,815,000 (53.2%) | **$27,175,000 (60.9%)** |
| **TOTAL** | **$9,419,000 (100%)** | **$1,050,000 (100%)** | **$27,010,000 (100%)** | **$7,174,000 (100%)** | **$44,653,000 (100%)** |
| King County Employment Effects (FTE's) | 40 | 5 | 100 | 20 | **165** |

*Values may not add due to rounding. Grey-filled cells indicate damage not modeled at that damage area / category combination.*

**Table 4-4. Tukwila / Dykstra Levee Breach Scenario, EAD by Damage Area and Category**

| | EAD by Damage Area and Damage Category ($) | | | | |
|---|---|---|---|---|---|
| **Damage Category** | Auburn (Upstream Left Bank) | Tukwila (Downstream Left Bank) | Kent/Renton (Right Bank) | Duwamish (Downstream) | **TOTAL** |
| Agricultural Crop Losses | $19,000 (1.8%) | | | | **$19,000 (0.1%)** |
| Damage to Passenger Vehicles and Trucks | $43,000 (4.0%) | $19,000 (0.2%) | $169,000 (1.8%) | $139,000 (4.1%) | **$370,000 (1.6%)** |
| Residential Structure & Contents Damages | $116,000 (10.8%) | $0,000 (0.0%) | $149,000 (1.6%) | $970,000 (28.7%) | **$1,235,000 (5.5%)** |
| Non-Residential Structure & Contents Damages | $821,000 (76.7%) | $8,582,000 (98.4%) | $8,925,000 (95.3%) | $2,058,000 (60.9%) | **$20,386,000 (90.5%)** |
| Cleanup Costs, Public Assistance Payments, and Utility Repairs | $17,000 (1.6%) | $117,000 (1.3%) | $81,000 (0.9%) | $212,000 (6.3%) | **$427,000 (1.9%)** |
| Freight Rail Detour Costs | $28,000 (2.6%) | | | | **$28,000 (0.1%)** |
| Vehicle Traffic and Passenger Rail Delay Costs | $26,000 (2.4%) | | $41,000 (0.4%) | | **$67,000 (0.3%)** |
| Lost Recreation Value | $0,000 (0.0%) | $0,000 (0.0%) | $1,000 (0.0%) | $1,000 (0.0%) | **$2,000 (0.0%)** |
| **Sub-Total** | **$1,070,000 (100%)** | **$8,718,000 (100%)** | **$9,366,000 (100%)** | **$3,380,000 (100%)** | **$22,534,000 (100%)** |
| NED Damage Categories Total | $1,070,000 (25.2%) | $8,718,000 (78.9%) | $9,366,000 (36.1%) | $3,380,000 (47.0%) | **$22,534,000 (46.5%)** |
| RED King County Regional Output Effect | $3,169,000 (74.8%) | $2,336,000 (21.1%) | $16,577,000 (63.9%) | $3,815,000 (53.0%) | **$25,897,000 (53.5%)** |
| **TOTAL** | **$4,239,000 (100%)** | **$11,054,000 (100%)** | **$25,943,000 (100%)** | **$7,195,000 (100%)** | **$48,431,000 (100%)** |
| King County Employment Effects (FTE's) | 20 | 20 | 100 | 20 | **160** |

*Values may not add due to rounding. Grey-filled cells indicate damage not modeled at that damage area / category combination.*

**Table 4-5. Horseshoe Bend Levee Breach Scenario, EAD by Damage Area and Category**

| | EAD by Damage Area and Damage Category ($) | | | | |
|---|---|---|---|---|---|
| **Damage Category** | Auburn (Upstream Left Bank) | Tukwila (Downstream Left Bank) | Kent/Renton (Right Bank) | Duwamish (Downstream) | **TOTAL** |
| Agricultural Crop Losses | $145,000 (4.4%) | | | | **$145,000 (0.9%)** |
| Damage to Passenger Vehicles and Trucks | $304,000 (9.1%) | $0,000 (0.0%) | $156,000 (1.5%) | $139,000 (4.1%) | **$599,000 (3.5%)** |
| Residential Structure & Contents Damages | $408,000 (12.3%) | $0,000 (0.0%) | $154,000 (1.5%) | $969,000 (28.8%) | **$1,531,000 (9.0%)** |
| Non-Residential Structure & Contents Damages | $1,935,000 (58.2%) | $21,000 (100.0%) | $9,845,000 (95.7%) | $2,049,000 (60.8%) | **$13,850,000 (81.5%)** |
| Cleanup Costs, Public Assistance Payments, and Utility Repairs | $100,000 (3.0%) | $0,000 (0.0%) | $90,000 (0.9%) | $212,000 (6.3%) | **$402,000 (2.4%)** |
| Freight Rail Detour Costs | $165,000 (5.0%) | | | | **$165,000 (1.0%)** |
| Vehicle Traffic and Passenger Rail Delay Costs | $266,000 (8.0%) | | $37,000 (0.4%) | | **$303,000 (1.8%)** |
| Lost Recreation Value | $1,000 (0.0%) | $0,000 (0.0%) | $1,000 (0.0%) | $1,000 (0.0%) | **$3,000 (0.0%)** |
| **Sub-Total** | **$3,324,000 (100%)** | **$21,000 (100%)** | **$10,283,000 (100%)** | **$3,370,000 (100%)** | **$16,998,000 (100%)** |
| NED Damage Categories Total | $3,324,000 (35.8%) | $21,000 (2.5%) | $10,283,000 (40.3%) | $3,370,000 (46.9%) | **$16,998,000 (39.7%)** |
| RED King County Regional Output Effect | $5,970,000 (64.2%) | $810,000 (97.5%) | $15,222,000 (59.7%) | $3,815,000 (53.1%) | **$25,817,000 (60.3%)** |
| **TOTAL** | **$9,294,000 (100%)** | **$831,000 (100%)** | **$25,505,000 (100%)** | **$7,185,000 (100%)** | **$42,815,000 (100%)** |
| King County Employment Effects (FTE's) | 40 | 5 | 90 | 20 | **155** |

*Values may not add due to rounding. Grey-filled cells indicate damage not modeled at that damage area / category combination.*

**Table 4-6. Meyers Golf Levee Breach Scenario, EAD by Damage Area and Category**

| | EAD by Damage Area and Damage Category ($) | | | | |
|---|---|---|---|---|---|
| **Damage Category** | Auburn (Upstream Left Bank) | Tukwila (Downstream Left Bank) | Kent/Renton (Right Bank) | Duwamish (Downstream) | **TOTAL** |
| Agricultural Crop Losses | $145,000 (4.4%) | | | | **$145,000 (0.8%)** |
| Damage to Passenger Vehicles and Trucks | $295,000 (9.0%) | $0,000 (0.0%) | $226,000 (2.0%) | $139,000 (4.1%) | **$660,000 (3.7%)** |
| Residential Structure & Contents Damages | $394,000 (12.0%) | $0,000 (0.0%) | $164,000 (1.5%) | $969,000 (28.8%) | **$1,527,000 (8.5%)** |
| Non-Residential Structure & Contents Damages | $1,920,000 (58.4%) | $23,000 (100.0%) | $10,774,000 (95.3%) | $2,039,000 (60.7%) | **$14,756,000 (82.1%)** |
| Cleanup Costs, Public Assistance Payments, and Utility Repairs | $99,000 (3.0%) | $0,000 (0.0%) | $90,000 (0.8%) | $211,000 (6.3%) | **$400,000 (2.2%)** |
| Freight Rail Detour Costs | $165,000 (5.0%) | | | | **$165,000 (0.9%)** |
| Vehicle Traffic and Passenger Rail Delay Costs | $266,000 (8.1%) | | $52,000 (0.5%) | | **$318,000 (1.8%)** |
| Lost Recreation Value | $1,000 (0.0%) | $0,000 (0.0%) | $1,000 (0.0%) | $1,000 (0.0%) | **$3,000 (0.0%)** |
| **Sub-Total** | **$3,285,000 (100%)** | **$23,000 (100%)** | **$11,307,000 (100%)** | **$3,359,000 (100%)** | **$17,974,000 (100%)** |
| NED Damage Categories Total | $3,285,000 (35.5%) | $23,000 (2.8%) | $11,307,000 (34.6%) | $3,359,000 (46.8%) | **$17,974,000 (36.0%)** |
| RED King County Regional Output Effect | $5,971,000 (64.5%) | $810,000 (97.2%) | $21,412,000 (65.4%) | $3,815,000 (53.2%) | **$32,008,000 (64.0%)** |
| **TOTAL** | **$9,256,000 (100%)** | **$833,000 (100%)** | **$32,719,000 (100%)** | **$7,174,000 (100%)** | **$49,982,000 (100%)** |
| King County Employment Effects (FTE's) | 40 | 5 | 140 | 20 | **200** |

*Values may not add due to rounding. Grey-filled cells indicate damage not modeled at that damage area / category combination.*

# 5. System-Wide Expected Annual Damage

The scenario weighting methodology outlined in Section 2.5 is applied here to develop a single estimate of system-wide expected annual damage. Table 5-1 summarizes the calculation.

**Table 5-1. System-Wide EAD Summary**

| | Scenarios | | | |
|---|---|---|---|---|
| | **Levee-Overtopping-then-Breach** | **Tukwila / Dykstra Levee Breach** | **Horseshoe Bend Levee Breach** | **Meyers Golf Levee Breach** |
| NED Damage Categories ($ EAD) | $17,478,000 | $22,534,000 | $16,998,000 | $17,974,000 |
| RED Total Output Effect ($ EAD) | $27,175,000 | $25,897,000 | $25,817,000 | $32,008,000 |
| Scenario Weights | 0.17 | 0.33 | 0.23 | 0.27 |
| Weighted NED ($ EAD) | $2,971,000 | $7,436,000 | $3,910,000 | $4,853,000 |
| Weighted RED ($ EAD) | $4,620,000 | $8,546,000 | $5,938,000 | $8,642,000 |
| **System-wide NED ($EAD)** | $19,170,000 | | | |
| **System-wide NED ($ PV)** | $449,644,000 | | | |
| **System-wide RED ($ EAD)** | $27,746,000 | | | |
| **System-wide RED ($ PV)** | $650,800,000 | | | |
| **System-wide NED+RED ($ EAD)** | $46,916,000 | | | |
| **System-wide NED+RED ($ PV)** | $1,100,444,000 | | | |

System-wide EAD for the NED damage categories was estimated to be $19.2 million, with a present value of $450 million. The RED damages were estimated to be an additional $27.7 million in EAD, or an additional present value of $651 million. Considering both the NED damages and the potential impacts on total output in the King County economy, EAD is estimated to be $47.0 million, or a present value of $1.1 billion dollars.

For a Corps of Engineers planning study, benefits of alternative are equivalent to reduction in flood damages they achieve. Therefore, the present value of the NED damages may be used as a gauge for the maximum project cost that could be supported to maintain a benefit-to-cost ratio of at least 1.0 if the project were to alleviate 100% of the flood risk.

However, most projects will alleviate only a portion of the flood risk, and residual risk of flooding will results in some damages even with the project in place. Because this analysis noted that overtopping is a driver of risk in the floodplain, it is likely that any proposed project would need to alleviate overtopping risk in order to capture a substantial portion of the $450 million dollars of potential benefits. In order to illustrate the methodology for estimating potential benefits of a project in terms of reduction in expected damages, Section 6 provides an abbreviated analysis of two flow-based level of protection considerations.

## 5.1. Interest Rate and Period of Analysis Sensitivity

As a matter of policy, Corps guidance states that a 50-year period of analysis is used on all projects except for major multi-purpose reservoir projects, when 100 years may be used. The Corps similarly requires a consistent interest rate, updated annually via an Economic Guidance Memorandum. The Federal Interest Rate for water resources planning is set based on the cost of federal government borrowing (Corps of Engineers 2000). The federally-specified period of analysis and interest rate was in calculations in order to remain consistent with Corps procedures.

However, variation in the period of analysis and interest rate can have substantial effects on the calculation of present value damages. Table 5-2 presents the results of a sensitivity analysis in which the present value of system-wide EAD was calculated for interest rates of 2.5% and 4%, and for a period of analysis of 75 and 100 years. These interest rates were selected to show a rate below and above the current federal rate of 3.5%. The period of analysis values were selected in order to evaluate the effects of a longer assumed project life.

**Table 5-2. Interest Rate and Period of Analysis Sensitivity**

| **System-Wide EAD ($)** | $46,916,000 | | |
|---|---|---|---|
| **Present Value Sensitivity** | | | |
| **Period of Analysis** | **Interest Rate** | | |
| | ***2.50%*** | ***3.50%*** | ***4.00%*** |
| **50** | $1,330,646,000 | $1,100,444,000 | $1,007,858,000 |
| **75** | $1,582,136,000 | $1,238,896,000 | $1,110,990,000 |
| **100** | $1,717,787,000 | $1,297,482,000 | $1,149,677,000 |
| ** Value matching Table 5-1* | | | |

# 6. Potential Project Benefits Analysis

One of the objectives of the Green River SWIF is to consider system-wide levels of projection. The potential for damage reduction associated with an increased level of protection based on the current conditions model can be used to help inform this topic. Two flows were considered for this analysis based on level of protection considerations for the SWIF, the flow and the 18,800 cfs (median, 0.2% AEP) flow. In order to evaluate the potential for damage reduction at the 15,100 cfs (high C.L., 1% AEP) event and at the 18,800 cfs (median, 0.2% AEP)event, HEC-FDA was used to model two level of protection (LOP) conditions.

The first level of protection condition consists of a hypothetical levee which has no risk of failure prior to overtopping and is constructed to a height equal to the HEC-FDA tabulated water surface elevation (i.e. no freeboard) for the 15,100 cfs (high C.L., 1% AEP) flow (at each location where breaches were modeled for the existing condition analysis). This condition is referred to as the 15,100cfs LOP. The second scenario is similarly defined but assumes levee heights that correspond to the 18,800 cfs (median, 0.2% AEP) flow. This scenario is referred to as the 18,800cfs LOP. For each LOP condition, the HEC-FDA model was run with the hypothetical levees in place, and the potential damage reduction was calculated by subtracting the post-project EAD from the existing condition EAD.

In order to define the hypothetical levee heights, stage elevation data was obtained from HEC-FDA outputs which reflects the hydraulic modeling inputs. Because the 18,800 cfs (median, 0.2% AEP) event corresponds to the 500-year median recurrence interval, levee height was obtained directly from the HEC-FDA output table for exceedance-stage at the 500-year recurrence. Because the 15,100 cfs (high C.L., 1% AEP) event is not a median flow, HEC-FDA output curves for flow-exceedance were first used to estimate a median recurrence interval for the 15,100 cfs flow, which was approximately 167 years. Next, the stage elevation for the 167 year recurrence was pulled from the HEC-FDA output table for exceedance-stage.

Table 6-1 summarizes the levee heights assumed for the analysis. As noted in the table, if the existing levee height exceeded the calculated hypothetical stage elevation, the existing levee height was used instead. Because this analysis is based on the index locations used in the evaluation of the existing condition scenarios, even if the existing levee was found to meet the calculated levee height in Table 6-1, there may be low points along the levee system that would require modification in order to achieve the modeled damage reductions that follow.

**Table 6-1. Hypothetical Levee Parameters**

| Damage Area | Existing Levee Height at Index Location | 15,100 cfs LOP Levee Heights | 18,800 cfs LOP Levee Heights | 18,800 vs 15,100 cfs Levee Height Difference |
|---|---|---|---|---|
| Auburn (upstream left bank) | 64.5 | 67.6 | 69.19 | 1.6 |
| Tukwila (downstream left bank) | 34.8 | 33.02 * | 34.11 * | 1.1 |
| Kent/Renton (right bank)' | 45.2 | 44.59 * | 45.94 | 1.4 |
| Duwamish (downstream) | 20.75 | 23.87 | 25.1 | 1.2 |
| ** Denotes levees where these existing condition levee exceeds the calculated hypothetical levee height. In these instances, the existing levee height was used.* | | | | |

HEC-FDA was run for each LOP condition in order to estimate EAD by damage area and system-wide. For each LOP model run, the same composite FLO-2D depth grids were used as with existing conditions. Table 6-2 and Table 6-3 present the damages reduced for each LOP condition by damage area. Table 6-4 presents the estimated present value of damages reduced for LOP condition.

**Table 6-2. EAD Damages Reduced for 15,100 cfs LOP Condition**

| Damages Reduced by Category | Auburn (Upstream Left Bank) | Tukwila (Downstream Left Bank) | Kent/Renton (Right Bank) | Duwamish (Downstream) | TOTAL |
|---|---|---|---|---|---|
| NED Total | $1,149,240 | $3,482,360 | $2,440 | $3,210,360 | **$7,844,400** |
| RED Total | $924,800 | $640,920 | $871,660 | $1,762,000 | **$4,199,380** |
| **TOTAL** | **$2,074,040** | **$4,123,280** | **$874,100** | **$4,972,360** | **$12,043,780** |
| *Values may not add due to rounding.* | | | | | |

**Table 6-3. EAD Damages Reduced for 18,800 cfs LOP Condition**

| Damages Reduced by Category | Auburn (Upstream Left Bank) | Tukwila (Downstream Left Bank) | Kent/Renton (Right Bank) | Duwamish (Downstream) | TOTAL |
|---|---|---|---|---|---|
| NED Total | $1,670,240 | $3,482,360 | $2,573,480 | $3,284,360 | **$11,010,440** |
| RED Total | $3,017,800 | $640,920 | $7,514,660 | $3,116,000 | **$14,289,380** |
| **TOTAL** | **$4,688,040** | **$4,123,280** | **$10,088,140** | **$6,400,360** | **$25,299,820** |
| *Values may not add due to rounding.* | | | | | |

**Table 6-4. Summary of EAD and PV of Damages Reduced**

| | 15,100 cfs LOP | 18,800 cfs LOP |
|---|---|---|
| **EAD Damages Reduced ($)** | | |
| NED | $7,844,000 | $11,010,000 |
| RED | $4,199,000 | $14,289,000 |
| Total | $12,043,000 | $25,299,000 |
| **PV Damages Reduced ($)** | | |
| NED | $183,986,000 | $258,246,000 |
| RED | $98,490,000 | $335,157,000 |
| Total | $282,476,000 | $593,404,000 |
| *3.5% interest rate and 50-year period of analysis.* | | |

As shown in Table 6-4, these two LOP conditions result in substantially different levels of damage reduction. Were levees to be raised to the water surface associated with the 15,100 cfs LOP, the present value of damages reduced would total $184 million for NED damages. For a federal planning study, total project cost to improve the levees could not exceed $184 million and maintain a benefit-to-cost ratio of 1.0. Including RED damage reduction, a total project cost of $282 million would be supported.

In the second scenario, if levees were raised to the water surface associated with the 18,800 cfs LOP, the present value of damages reduced would support $258 million of project construction cost and still maintain a benefit-to-cost ratio of at least 1.0. Including RED damage reduction, $593 million of construction would be supported.

In addition to EAD, HEC-FDA reports levee project performance statistics, a key component of which is conditional non-exceedance probability by event. Conditional non-exceedance probability is the likelihood that a given levee will contain (will not be exceeded by) a given recurrence interval event in any year of the period of analysis. HEC-FDA generates this statistic inclusive of the uncertainty about the exceedance-discharge curve, the stage-discharge curve, and the levee-fragility curve. The conditional non-exceedance probability for the 1% chance event (100-year) and 0.2% chance event (500-year) are summarized below, noting that the 1% chance and 0.2% chance events do not correspond to specific flows, but are inclusive of uncertainty in the hydraulics.

**15,100 cfs Water Surface Levee Heights Scenario**

- For the 1% chance event, the hypothetical levees associated with the Auburn and Duwamish damage areas have an 83% likelihood of containment; the Tukwila levee (same as existing levee) has a 98% likelihood of containment, and the Kent/Renton levee has an 86% likelihood of containment.
- For the 0.2% chance event, the Auburn and Duwamish damage area levees have a less than 40% likelihood of containment, and the Kent/Renton damage area has a 50% chance of containment, and the Tukwila levee has a 91% chance of containment.

**18,800 cfs Water Surface Levee Heights Scenario**

- If the hypothetical levee were constructed to a height equal to the 18,800 cfs (median , 0.2% AEP) stage in each damage area, all damage area levees would have a 95% or greater likelihood of containing the 1% chance event.
- For the 0.2% chance event, the Tukwila damage area would maintain a 91% likelihood of containing the event, while the other three damage areas would have about a 70% likelihood of containing the event.

# 7. FINDINGS & LIMITATIONS

The following bullets summarize the findings of this economic analysis as well the limitation of the results.

## 7.1. ANALYSIS

- **Flood Flow Range Considered:** The economic evaluation of flood risk has included consideration of potential levee breach locations along with overbank flooding and levee overtopping throughout the system for a range of flood events up to and including flows of 26,800 cfs.
- **Existing Condition Scenarios:** Four existing condition scenarios, three levee breach scenarios and one levee-overtopping-then-breach scenario, were modeled and combined to characterize existing condition flood risk. Geotechnical and hydraulic parameters are inputs to the economic model which tabulates damage in the floodplain corresponding to various levels of flood stage then converts these estimates to an expected annual flood damage.
- **Inclusion of Uncertainty:** The existing condition scenarios were evaluated at the system-wide level consistent with Corps of Engineers risk and uncertainty guidance for planning studies. The four existing condition scenarios characterize risk of flood damage from geotechnical levee breaches at four representative locations and the risk of flood damage from levees overtopping.
- **Damage Accounts:** Flood damages and impacts are characterized into two broad categories or accounts, National Economic Develop (NED) effects and Regional Economic Development (RED) effects. The NED account displays changes in the economic value of the national output of goods and services. The RED account displays the regional and localized economic impacts that are transfers from the federal perspective.
    - NED damage categories included damage to residential, commercial, and public structures and contents; damage to passenger vehicles and commercial vehicles; post-

flood cleanup, public assistance, and utility repair costs; vehicle traffic and passenger rail delay costs; freight rail detour costs; agricultural crop losses; and lost recreation value.
    - RED damages (regional economic impacts) were evaluated using regional input-output modeling. Impacts represent reduced output (sales/gross revenue) that would occur in King County due to temporary reduction of employment due to closure of businesses following inundation for cleanup and repair.
    - Loss of life and other social effects were outside the scope of the flood risk assessment.
- **System-wide EAD:** The resulting expected annual damage estimates for each of the four scenarios were weighted according to their likelihood of occurrence in order to provide a single system-wide estimate of existing condition expected annual flood damages.
- **Potential Project Benefits Analysis:** Following development of the economic models for the existing condition evaluation, an analysis was conducted to estimate the potential damages reduced and conditional non-exceedance probability for two levels of protection (LOP); levee design height at the stage associated with the 15,100 cfs flow, and levee design heights at the stage associated with the 18,800 cfs flow.

## 7.2. FINDINGS

- **EAD Estimates for Four Existing Condition Scenarios:** The HEC-FDA modeling resulted in EAD for the NED categories of between $17.0 and $22.5 million dollars. The EAD for RED damages based on IMPLAN modeling varies from $25.8 to $32 million dollars.
- **System-wide EAD Estimate:** The NED damage categories was estimated to be $19.6 million, with a present value of $460.7 million. The RED damages were estimated to be an additional $27.5 million in EAD, or an additional present value of $645.3 million. Considering both the NED damages and RED damages, EAD is estimated to be $47.2 million, or a present value of $1.1 billion dollars.
- **Potential Project Benefits for 15,100 cfs LOP:** Potential damage reduction for an increased level of protection, where levee design height is set at the water surface associated with the 15,100 cfs flow (without freeboard), resulted in a present value of damages reduced of $184 million for NED damages. For a federal planning study, total project cost to improve the levees could not exceed $184 million and maintain a benefit-to-cost ratio of 1.0. Including RED damage reduction of an additional $98 million, a total project cost of $282 million would be supported. For this LOP consideration, the likelihood of containment for the 1% and 0.2% chance flood events across the full range in confidence limits varies by area. For the 1% chance event (100-year), the hypothetical levees associated with the Auburn and Duwamish damage areas have an 83% likelihood of containment; the Tukwila levee (same as existing levee) has a 98% likelihood of containment, and the Kent/Renton levee has an 86% likelihood of containment. For the 0.2% chance event (500-year), the Auburn and Duwamish damage area levees have a less than 40% likelihood of containment, and the Kent/Renton damage area has a 50% chance of containment, and the Tukwila levee has a 91% chance of containment.
- **Potential Project Benefits for 18,800 cfs LOP:** Potential damage reduction for an increased level of protection, where levee design height is set at the water surface associated with the 18,800 cfs flow, resulted in a present value of damages reduced of $258 million for NED damages. Including RED damage reduction of an additional $335million, $593 million of construction would be supported. For this LOP consideration all levees in the system would have a 95% chance or greater of containing the 1% chance flood event. For the 0.2% chance event, the

Tukwila damage area would maintain a 91% likelihood of containing the event, while the other three damage areas would have about a 70% likelihood of containing the event.

## 7.3. LIMITATIONS

### 7.3.1. HEC-FDA

- **HEC-FDA resolution:** HEC-FDA relies on a structure inventory which classifies structures according to established depth-damage functions. This expedited analysis relied on best available data and results in an inventory which represents the floodplain on average, but may not accurately represent specific structures/facilities.
- **Hydraulic modeling:** Based on available information during model development, the models were constructed with the understanding that the largest flows to be modeled were less than 14,000 cfs due to the regulation of HHD. Further, calibration data were only available for floods of 12,400 cfs and lower. Thus no calibration data was available for the larger floods to provide validation of the accuracy of the models overbank simulations.
- **Geotechnical Assessment:** The geotechnical assessment was limited to the PL 84-99 levee system and existing information.
- **Geographic Scale of Results:** The defined existing condition scenarios are intended to characterize system-wide risk based on representative failure locations. Damages at small-scale geographies would be expected to vary depending on the actual failure location.
    - Model results are intended to estimate expected annual flood damages at a resolution sufficient for identification of system-risk level, as well as future efforts to evaluate and compare the relative effectiveness of alternative plans. The HEC-FDA model is not intended to facilitate structure or facility-specific damage estimates.

### 7.3.2. REGIONAL ECONOMIC ANALYSIS (IMPLAN)

- **Downtime:** Estimates of lost regional output are derived from estimates of employment reduction during downtime following a flood. Downtime was estimated for six depth levels and applied to all businesses; downtime is not industry specific.
- **Relocation Assumptions:** The analysis assumes that all businesses will remain in the floodplain and re-open following the closure downtime. Were businesses to relocate elsewhere in King County immediately following a flood, total impacts might be reduced. However, if businesses were to relocate outside the County, impacts to the King County economy might persist over the long term.
- **Business Benefits:** This analysis does not reflect any beneficial effects to those businesses which might see an increase in output following a flood event (clean-up / restoration services, construction industries, etc.).

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King County

# GREEN RIVER, KING COUNTY, WASHINGTON
# SYSTEM WIDE IMPROVEMENT FRAMEWORK (SWIF)

Photo Credit: USACE

# HOWARD HANSON DAM

# PRELIMINARY CAPACITY EVALUATION

## FINAL

## SEPTEMBER 3, 2014

King County

# GREEN RIVER SWIF

# HOWARD HANSON DAM

# PRELIMINARY

# CAPACITY EVALUATION

**FINAL**

**SEPTEMBER 2014**

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# 1. BACKGROUND

## 1.1. PROJECT DESCRIPTION

Howard Hanson Dam (HHD), a multi-purpose project constructed and operated by the U.S. Army Corps of Engineers (Corps of Engineers) was originally authorized in 1950 by Congress for the principal purpose of flood control. Other project purposes include low flow augmentation, ecosystem restoration and municipal and industrial water supply. The Project, which began operating in 1961, includes a 235 foot high, 675 foot long earthen embankment and abutment, outlet works, spillway and reservoir (see cover photo). The reservoir impounded by the dam is referred to as Eagle Gorge Reservoir.

Figure 1-1 shows a schematic representation of HHD and the elevations for specific design features of the dam. The outlet works consists of a gate tower and intake structure with two radial gates, a concrete horseshoe-shaped outlet tunnel, a gate-controlled bypass, and a stilling basin. The spillway is a gate-controlled concrete ogee overflow section with a downstream concrete-lined chute and a crest elevation of 1176.0 feet; it has never been used. Eagle Gorge Reservoir is approximately 4 miles long at the conservation pool elevation of 1141.0 feet above mean sea level relative to the National Geodetic Vertical Datum of 1929 (NGVD29), which corresponds with 25,400 acre-feet of storage. The maximum full pool elevation for the reservoir is 1206 feet NGVD29, which provides up to 106,000 acre feet of storage. For most flood events, operations would be managed so as not to exceed this elevation. The pool elevation associated with the probable maximum flood (PMF) event is 1223.9 feet (NGVD29). This is also referred to as the spillway design flood event is). The record pool elevation to date occurred during the January 2009 flood event and was 1188.8 feet.

In 1996, a Section 1135 project for low-flow augmentation was authorized, raising the summer conservation pool to elevation 1147.0 feet. In 1999, a significant modification to the original Project was authorized to support water supply and ecosystem restoration. Both projects required a non-federal sponsor who cost shares study and implementation costs with the Corps of Engineers. Tacoma Public Utilities is the non-federal sponsor for both projects. Referred to as the Additional Water Storage Project (AWSP), it included two phases. Phase 1, which has been partially implemented, provides an additional 20,000 acre-feet for Municipal and Industrial (M&I) water supply for Tacoma; it raises the conservation pool to an elevation of 1167.0 feet for M&I purposes and includes features for ecosystem restoration and compliance with the Endangered Species Act. Phase 2 would store an additional 12,000 acre-feet of water and raise the pool elevation to 1177.0 feet in the spring for release during the summer and fall. The summer conservation period is specifically designated as March through September, but low-flow augmentation typically occurs from June to October. Completion of Phases 1 and 2 is dependent on reauthorization of the Project because the current estimated costs exceed the amount authorized. The AWSP also requires re-consultation under Section 7 of the Endangered Species Act and re-formulation of upstream fish passage facilities.

## 1.2. PROJECT OPERATIONS

During the fall and winter months the Project is operated by the Corps of Engineers for flood risk management, while during the spring and summer, operations are aimed at water conservation for low

flow augmentation. Flood risk management operations are the subject of this capacity evaluation and are described in more detail below.

Between October and February, when the threat of flooding is high, the reservoir pool is held at a low level to maximize available storage during flood events. Between December 1 and February 15, the reservoir pool is drawn down to its lowest elevation, which is elevation 1075 feet (NGVD29), to maximize available storage during flood events.

During a flood event, HHD outflows are regulated based on the hydrologic conditions at a downstream control point, which is the USGS gage at Auburn. The maximum regulated target flow rate at the control point is 12,000 cubic feet per second (cfs), which represents the approximate channel capacity of the river at the control point. The contributing drainage area at the dam site is 221 square miles (sq mi) and the contributing drainage area at the control point is 399 sq mi. Therefore, nearly 45 percent of the watershed at the control point is unregulated drainage area. These discharges, referred to as local inflows, are variable and are not necessarily correlated with upper basin flows. Due to the forecast uncertainty of the local inflows, the maximum flow rate at the Auburn gage is targeted to not exceed 10,000 cfs on the rising limb of the flood event. This provides a buffer that helps to ensure flows do not exceed the 12,000 cfs maximum regulated target flow rate. While generally sufficient, flows have exceeded 12,000 cfs three times since the project has been in operation, an indication of the local inflow uncertainty dam operators must deal with. During a flood event, once the downstream local inflow hydrograph has peaked, forecast uncertainty is greatly reduced, and Project releases are increased to target a maximum flow of 12,000 cfs in an effort to evacuate storage in the reservoir as rapidly as practicable. The following bullets summarize key reservoir pool elevations along with project operation considerations at the different elevations which are also shown on Figure 1-1. Corresponding storage volumes are provided in parentheses.

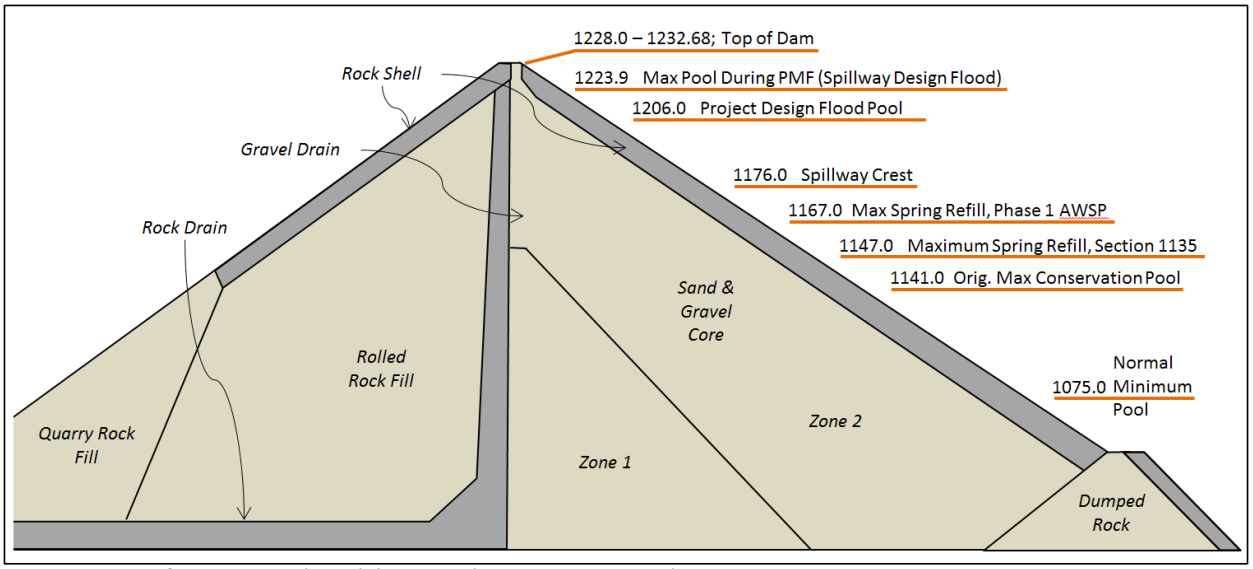
- **Elevation 1075.0 feet**: Elevation maintained during flood season to provide full storage capability.
- **Elevation 1141.0 feet** (25,375 acre-feet): Elevation of originally authorized maximum conservation pool.
- **Elevation 1147.0 feet** (30,395 acre-feet): Elevation of maximum spring reservoir filling after implementation of Section 1135 storage.
- **Elevation 1167.0 feet** (50,450 acre-feet): Elevation of maximum spring refill with Phase 1 of the AWSP project, first implemented in 2007.
- **Elevation 1177.0 feet** (62,350 acre-feet): Elevation of maximum spring refill of the proposed Phase 2 AWSP. Storage volume is.
- **Elevation 1206.0 feet**: (105,463 acre-feet): Elevation of the normal full reservoir pool. Storage volume is 105,463 acre-feet.
- **Elevation 1223.9 feet** (136,700 acre-feet): Maximum elevation of the reservoir during the probable maximum flood (PMF)

During very large flood events, it is possible that the 12,000 cfs regulation target flow will be exceeded at the USGS gage at Auburn. This can happen if the inflow volume for the flood event is so large that the pool elevation at HHD threatens to exceed the 1206 ft (NGVD29) maximum full pool elevation as Project outflows are being regulated to maintain the target flow rate at the USGS gage at Auburn.

Figure 1-2 is an example of a theoretical operation of HHD during such an event. As shown in this figure, the reservoir pool starts at elevation 1075 feet (NGVD29) and increases in elevation as outflows from HHD are reduced to maintain the 10,000 cfs target flow rate at Auburn. Regulation using only this

procedure could result in premature filling of the reservoir, potentially requiring Project outflows that would exceed those that would have occurred under pre-Project conditions. Therefore, for these very large flood events, Project outflows are increased as required by the Discharge Regulation Schedule (DRS), resulting in regulated discharges at Auburn that exceed 12,000 cfs. The DRS is used to determine the maximum release rate for very large floods that might otherwise result in a reservoir elevation in excess of the design conditions. The DRS operation protocol is used to manage the use of the flood control volume and to prevent uncontrolled releases from the Project. It uses knowledge of the inflow rate to the reservoir or rate of rise of the reservoir to determine the flood severity and adjust outflow accordingly. The result of implementing the DRS during a very large flood event is illustrated in Figure 1-2 by the sharp increase in HHD outflow during the second day of the event. It is seen that implementation of the DRS occurs on the rising limb of the inflow hydrograph. Because the purpose of the DRS is to manage the use of the flood control pool during large flood events, it is seen that the DRS is implemented even though there is still flood storage capacity remaining in the reservoir. In this example, implementation of the DRS resulted in a managed use of the flood control pool such that the maximum pool elevation was 1,207 feet NGVD29 and while the maximum regulated peak flow rate at Auburn was approximately 19,200 cfs.

For very large flood events, when the maximum full pool elevation has been exceeded, such as occurs in the example in Figure 1-2, evacuation of the reservoir does not begin until the flow rate at Auburn has dropped to 12,000 cfs. In this figure, it is seen that reservoir evacuation begins on the sixth day of the flood event and it is seen that the HHD releases are made to maintain the 12,000 cfs target flow rate during this evacuation.




Maximum Section of Dam, Not to Scale; Pool Elevations Relative to NGVD29 Vertical Datum

**Figure 1-1. Howard Hanson Dam Project Elevations**

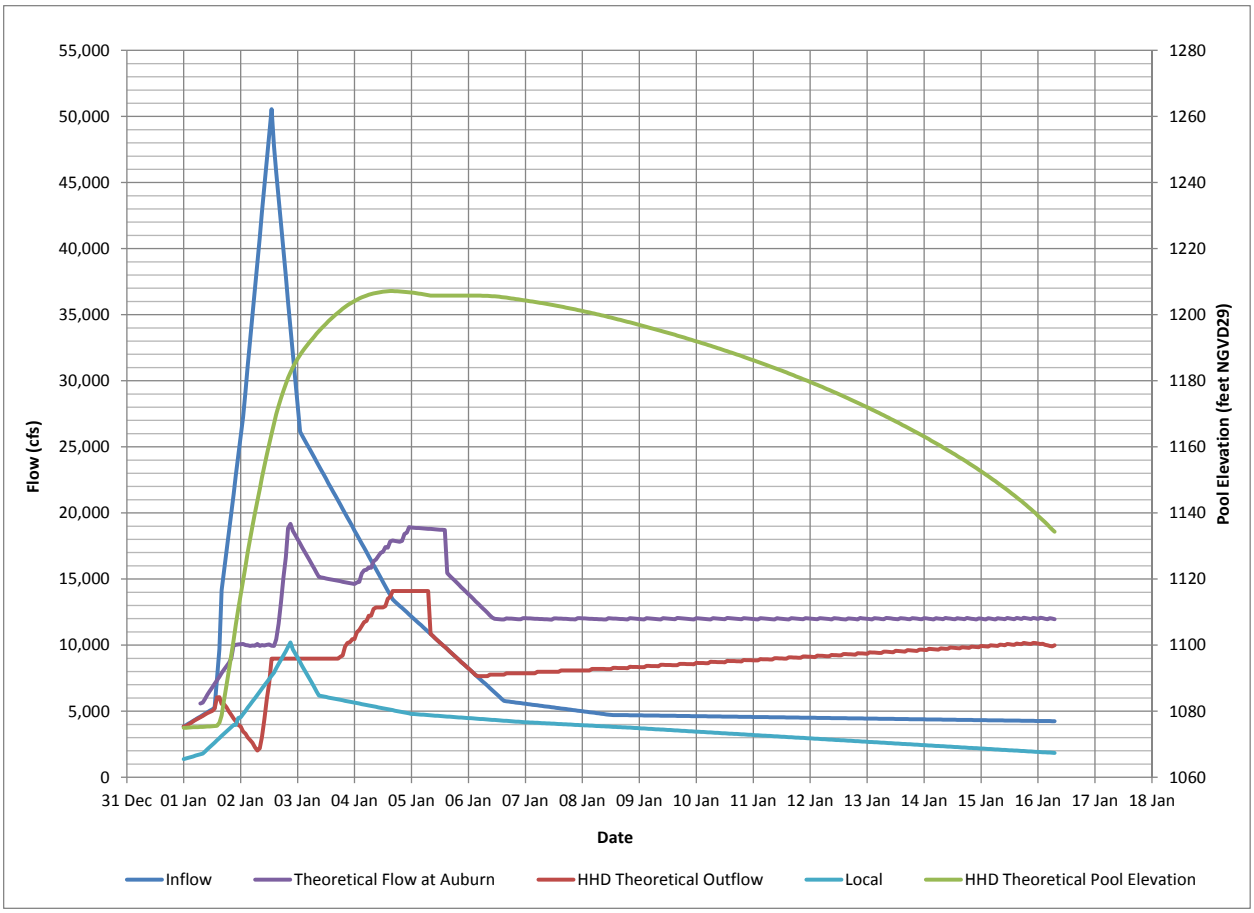



**Figure 1-2. Hypothetical HHD Operations Model Results**

## 1.3. Design Flood Hydrographs

In 2012, the Corps of Engineers completed a study (Corps of Engineers 2012) that developed flood hydrographs for the lower Green River at the location of the Auburn USGS gage for seven design flood events ranging from the 50% Annual Exceedance Probability (AEP) flood event (2-yr return period) to the 0.2% AEP flood event (500-yr return period).

Prior to this study it was believed that flood management regulation of HHD could maintain the 12,000 cfs regulation target up to flood events with a 0.2% Annual Exceedance Probability (AEP), which is synonymous with a 500-year return period flood event. However, the recent study (Corps of Engineers 2012) concluded instead that the dam can only be operated to meet the target flow for flood events up to around a 0.71% AEP (140-year) flood event.

One of the objectives of the Green River SWIF is to consider an increase in the level of protection from flooding in the Lower Green River. Flood risk management is currently provided by the system of levees and revetments between River Mile 32 and River Mile 11 in combination with operation of HHD. There is a need to agree on a desired level of protection for the Green River, and determine how this protection can be provided by levee improvements, possibly in conjunction with HHD operation or structural modifications.

# 2. PURPOSE

The purpose of this task is to conduct a preliminary analysis of conditions at HHD to determine if there are operational or structural modifications that could provide regulation of higher magnitude flood events. The outcome of the analysis is an initial assessment that will be used to inform a decision about whether further study should be pursued or is warranted.

# 3. APPROACH

The task approach includes a limited initial technical analysis and implementation considerations to support a decision about whether to further pursue studies associated with potential modifications to HHD. Three options have been identified to inform the initial assessment which includes two operational options and one structural option. The two operational changes were identified to assess potential opportunities, if further studies were to be pursued additional operational options would be assessed. Operational changes could also be considered in combination with increases in level of protection that are under evaluation for levees in the Lower Green River.

## 3.1. LIMITATIONS

Flood regulation at HHD is complex and there are many factors beyond the scope of this preliminary analysis that would require additional studies. These include but are not limited to environmental studies and environmental compliance requirements associated with potential impacts or changes. Engineering feasibility studies would also be required with any type of modification. The scope of engineering studies required would need to be determined by the Corps of Engineers. However engineering studies would likely include detailed hydraulic studies as well as dam safety studies and studies related to specific project features and operation. Structural and some operational changes would also likely require legal assessment to determine whether an action is within the scope of the existing authorization. Some project specific constraints are further outlined in Section 4.2. This preliminary analysis is focused on operations and operating requirements at the dam and does not address downstream effects or physical changes at HHD. The following sections briefly outline the evaluation approach for each option.

## 3.2. DESCRIPTION OF OPTIONS

**Option 1 (Operational Change)** – This option considers the effect of increasing the magnitude of the releases made from HHD on the rising limb of the flood hydrograph, such that the maximum target flow rate at Auburn would be 12,000 cfs. Under current operation, discharges from HHD are regulated to control flows at Auburn to a maximum flow of 10,000 cfs on the rising limb so as to provide a margin of safety against errors in forecasted local inflows (Corps of Engineers 2011). This option does not consider any changes to the 12,000 cfs target flow once the local inflow hydrograph has peaked.

**Option 2 (Operational Change)** – This option considers the effect of increasing the regulated target flow rate from the existing 12,000 cfs in order to improve the ability of HHD to maintain regulation for higher magnitude flood events. The target flow rate was increased to 15,100 cfs, with a 13,100 cfs target flow rate on the rising limb of the flood hydrograph for this assessment. The downstream impacts to the Middle and Lower Green River and floodplain resulting from this operational modification are not quantified for this evaluation but would need to be addressed if this option were to be recommended for further study.

**Option 3 (Structural Change)** – This option considers the effect of increasing the 1206 foot (NGVD29) full pool elevation and the height of the dam on the ability of HHD to maintain regulation for higher magnitude flood events. This option includes a number of simplifying assumptions based on the complexity of Project operations. It will quantify the *minimum* full pool elevation required for HHD to fully regulate the 0.2 % AEP Median flood event. This option assumes that maximum target flow rate at Auburn would not change from existing operational conditions. This option focuses on operating requirements

## 3.3. Approach for Analyzing Options

### 3.3.1. Options 1 and 2 (Operational Options)

The technical approach for evaluating the two operational options used the Corps of Engineers HHD Operation Model to determine the regulated HHD outflow hydrographs. This model uses a Microsoft Excel based platform, and is used by the Corps of Engineers to determine Project outflows during real-time operations. The balanced hydrographs developed by the Corps of Engineers (Corps of Engineers 2012) were used as inputs to this model. Operations modeling was performed using the procedures outlined in the Water Control Manual for HHD (Corps of Engineers 2011) along with the changes in operation as proposed for each option. The regulated HHD outflow hydrographs determined from the operations model were then hydraulically routed from HHD to the Auburn Gage using the same 1-D unsteady HEC-RAS model that was used by the Corps of Engineers for their study (Corps of Engineers 2012).

In addition to the technical analysis outlined above; policy, process and implementation considerations are also described for these operational changes.

### 3.3.2. Option 3 (Structural Option)

A complete technical evaluation of this option would require development of a new DRS for the increased full pool elevation and a revision to the HHD Operation Model to include this updated DRS. This work effort was beyond the scope of this study. Therefore, in lieu of developing a new DRS for a new full pool elevation and evaluating HHD operations under this new changed condition, a lesser detailed technical approach was used. The approach used the HHD Operation Model to determine the *minimum* full pool elevation required for HHD to fully regulate the 0.2% AEP Median flood event. This was accomplished by assuming that HHD Project outflows are regulated to the target control flow at Auburn for the duration of this flood event. This means that on the rising limb of the flood event, HHD Project outflows were regulated to the 10,000 cfs target control flow, and once the downstream local tributary hydrograph peaked, HHD Project outflows were regulated to the 12,000 cfs target control flow.

The routed peak reservoir elevation resulting from this analysis represents the *minimum* full pool elevation required to fully regulate this flood event. In reality, the actual required full pool elevation

would need to be much higher in order to maintain the regulated target flows without triggering the need for outflows to be determined from a DRS.

In addition to the limited technical analysis outlined above; policy, process and implementation considerations are also described for these structural changes.

# 4. Analysis & Findings

The following sections summarize the analytical results for each of the three options as well as the policy and implementation considerations for the operational or structural modifications required at HHD.

## 4.1. Technical Analysis Results

Analysis results for Option 1 and Option 2 are presented in tabular format (see Table 4-1) and graphical format (see Figures 4-1 and 4-2) and are described in detail in Sections 4.1.1 and 4.1.2.

Table 4-1 shows the simulated regulated peak flow in the Green River at Auburn for the existing operation condition. These values were obtained from the Corps of Engineers (2012) study. The simulated regulated peak flow at Auburn for each of Option 1 and Option 2 are then shown in the two columns on the right side of the table. The shaded cells in this table indicate those flood events with peak flows greater than the target flow rate at Auburn.

The analysis results for Option 3 (Structural Option) are described in Section 4.1.3.

**Table 4-1: Simulated Regulated Peak Flows at Auburn for Existing Conditions and Options 1 and 2**

| Flood Event Annual Exceedance Probability | Confidence Level | Simulated Regulated Peak Flow at Auburn (cfs) | | |
|---|---|---|---|---|
| | | Existing (Target Flow 12,000 cfs) | Option 1 (Target Flow 12,000 cfs) | Option 2 (Target Flow 15,100 cfs) |
| 0.2% (500-yr) Flood | Median | 18,800 | 18,300 | 17,500 |
| | High Confidence Limit (5%) | 26,800 | 26,000 | 25,700 |
| | Low Confidence Limit (95%) | 12,000 | 12,000 | 15,100 |
| 0.5% (200-yr) Flood | Median | 12,600 | 12,600 | 15,100 |
| | High Confidence Limit (5%) | 20,000 | 19,300 | 19,000 |
| | Low Confidence Limit (95%) | 12,000 | 12,000 | 15,100 |
| 1% (100-yr) Flood | Median | 12,000 | 12,000 | 15,100 |
| | High Confidence Limit (5%) | 15,100 | 14,200 | 15,100 |
| | Low Confidence Limit (95%) | 12,000 | 12,000 | 15,100 |
| 2% (50-yr) Flood | Median | 12,000 | 12,000 | 15,100 |
| | High Confidence Limit (5%) | 12,000 | 12,000 | 15,100 |
| | Low Confidence Limit (95%) | 12,000 | 12,000 | 15,100 |
| 4% (25-yr) Flood | Median | 12,000 | 12,000 | 15,100 |
| | High Confidence Limit (5%) | 12,000 | 12,000 | 15,100 |
| | Low Confidence Limit (95%) | 12,000 | 12,000 | 15,100 |
| 10% (10-yr) Flood | Median | 12,000 | 12,000 | 15,100 |
| | High Confidence Limit (5%) | 12,000 | 12,000 | 15,100 |
| | Low Confidence Limit (95%) | 11,900 | 11,900 | 15,100 |
| 50% (2-yr) Flood | Median | 9,200 | 9,200 | 9,200 |
| | High Confidence Limit (5%) | 9,900 | 9,900 | 9,900 |
| | Low Confidence Limit (95%) | 9,200 | 9,200 | 9,200 |

Note: The shaded cells indicate those flood events with peak flows greater than the target flow rate at Auburn

### 4.1.1. Option 1 (Operational Change)

The reservoir operation and hydraulic analysis focused only on the five flood events that were not regulated to the 12,000 cfs target flow at Auburn under existing operational conditions, as shown in Table 4-1. This included the 0.2% AEP High C.L, the 0.5% AEP High C.L., the 0.2% AEP Median, the 1% AEP High C.L, and the 0.5% AEP Median flood events. Focusing on these events was appropriate because the goal of the analysis was to determine the extent to which changes in HHD operation would reduce regulated Green River peak flows for the flood events that will likely factor into Level of Protection (LOP) decision making.

The analysis was not conducted for the flood events that were regulated to the 12,000 cfs target flow under the existing operation conditions (see Table 4-1). Instead, it was assumed for these events that the change in operation would either result in no change in the regulated peak flow at Auburn (i.e. the regulated peak flows would remain as 12,000 cfs), or that the regulated peak flows would be slightly reduced below the 12,000 cfs. This is because the 12,000 cfs regulated peak flow for these flood events for the existing conditions is a result of HHD evacuating storage after the flood peak has passed.

As seen in Table 4-1, the regulated peak flow for the five flood events that were analyzed was reduced as a result of the change in operations. The reduction, however, was small and on the order of 500 cfs to 900 cfs for any given flood event. For example, the regulated peak flow for the 0.2% AEP High C.L. under existing conditions was 26,800 cfs, while under Option 1, it would be 26,000 cfs.

The reason for this small reduction was primarily due to the fact that the increase in target flow rate (from 10,000 cfs to 12,000 cfs) preserved only a small amount of flood storage volume in the reservoir on the rising limb of the flood event. For the large flood events that were analyzed, HHD operations met the target flow rate for approximately a 20 hour period before HHD outflows had to be reduced as per the DRS. Over this 20 hour period, the 2,000 cfs increase in Project outflows equated to only 3,300 acre-feet of flood control volume not used on the rising limb, which is a small percentage (3%) of the 106,000 acre feet of authorized flood control volume. Ultimately, the small change in the target flow rate was not enough to prevent the need for using the DRS to determine Project outflows during the peak of the flood events, although it was enough to slightly reduce the flow magnitudes required by the DRS as compared to existing conditions.

Figure 4-1 shows a graphical representation of the results, comparing the regulated flood frequency curves for Option 1 against existing conditions. It is seen that the regulated flood frequency for the 95% confidence limit (Low C.L.) did not change. The change in operations did result in a modest reduction in regulated peak flows for the median and 5% confidence limit (High C.L.) curves, most notably for the 5% confidence limit (High C.L.) curve.

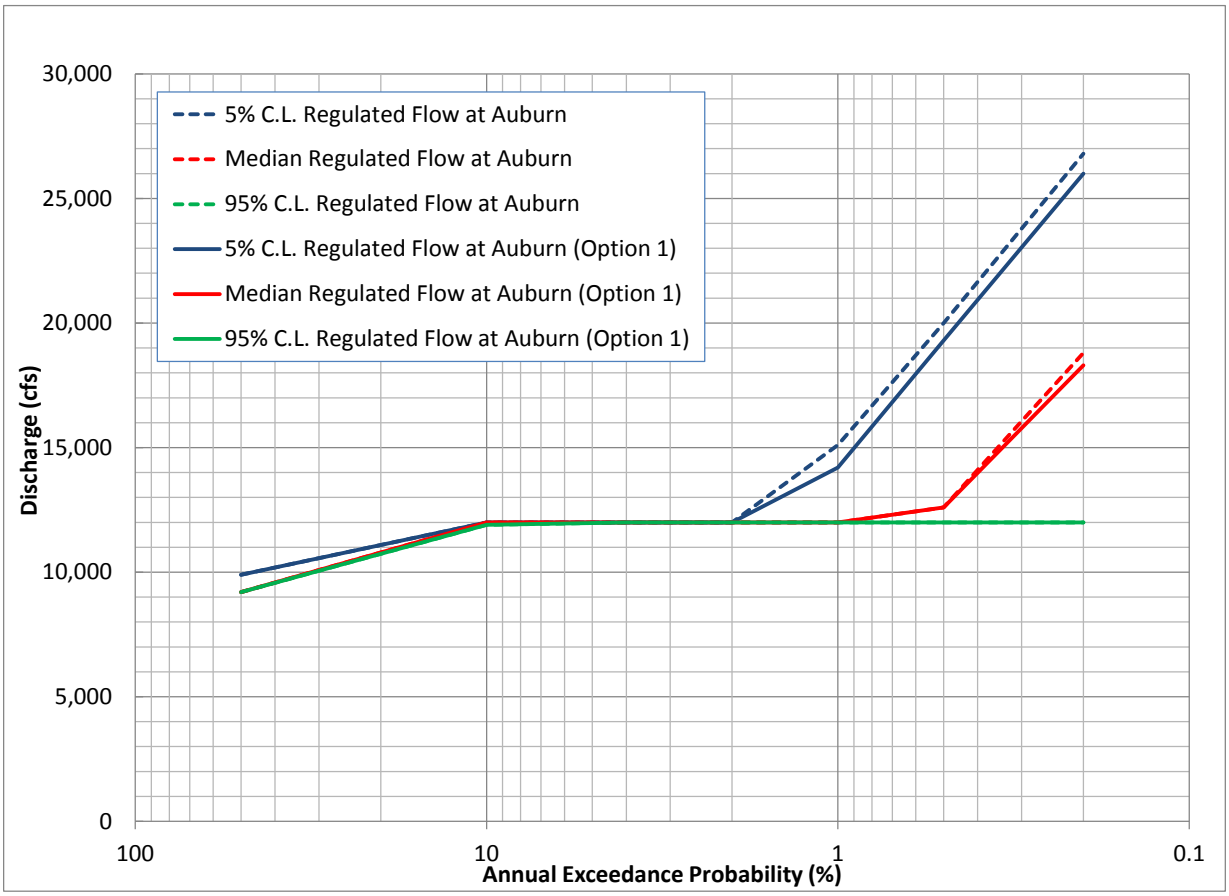



**Figure 4-1: Discharge vs Annual Exceedance Probability & Flood Frequency at Auburn for Option 1**

### 4.1.2. Option 2 (Operational Change)

For the same reason as for Option 1, the reservoir operation and hydraulic analysis focused only on the five flood events that were not regulated to the 12,000 cfs target flow at Auburn under existing operational conditions, as shown in Table 4-1. This included the 0.2% AEP High C.L, the 0.5% AEP High C.L., the 0.2% AEP Median, the 1% AEP High C.L, and the 0.5% AEP Median flood events. The analysis was conducted in descending order of flood event magnitude for each of the High C.L, Median and Low C.L. sets of flood events to determine the largest flood events that would be regulated to the new 15,100 cfs target flow rate. The results are shown in Table 4-1. For the Low C.L. set of flood events, it was found that all floods up to and including the 0.2% AEP could be regulated to the 15,100 cfs target flow rate. For the Median set of flood events, it was found that all floods up to and including the 0.5% AEP flood event could be regulated to the 15,100 cfs target flow rate. Finally, for the High C.L. set of flood events, it was found that all floods up to and including the 1% AEP could be regulated to the 15,100 cfs target flow rate.

Based on the analysis results for these high flow flood events, it was assumed that HHD could regulate all flood events less than these threshold flood events to a peak flow at Auburn of no more than the 15,100 cfs target flow.

As seen in Table 4-1, it was determined that the regulated peak flow rate at Auburn exceeded the 15,100 cfs target flow rate for only the three largest flood events. For each of these three flood events, the reduction in regulated peak flow rate at Auburn, as compared to existing conditions, ranged between 1,000 cfs (for the 0.5% AEP High C.L.) and 1,300 cfs (for the 0.2% AEP Median). For each of these three flood events, Project outflows during the peak of the flood event were determined from the DRS, which is also used for existing conditions. Similar to Option 1, the reason the regulated peak flow rates were reduced relative to existing conditions is because the higher magnitude target flow rate reduced the amount of flood control volume that was used on the rising limb of the flood event, thus reducing the minimum required flow rates on the DRS during the peak of the flood event.

Figure 4-2 shows a graphical representation of the results, comparing the regulated flood frequency curves for Option 2 against existing conditions. It is seen that the Option 2 regulated flood frequency curve for the 95% confidence limit (Low C.L.) shows that all flood events could be regulated to the 15,100 cfs target flow rate. The median regulated flood frequency curve shows that all flood events less than or equal to the 0.5% AEP flood event (200-yr) could be regulated to the new 15,100 cfs, and that the regulated peak flow rate for the 0.2% AEP flood event (500-yr) is slightly less than existing conditions. The regulated flood frequency curve for the 5% confidence limit (High C.L.) shows that all flood events less than or equal to the 1% AEP could be regulated to the new 15,100 cfs, and that the regulated peak flow rates for the 0.5% AEP (200-yr) and 0.2% AEP flood event (500-yr) are slightly less than existing conditions.

The preliminary analysis of Option 2 did not consider downstream impacts of the higher regulated flow peak flows. If this option were to be pursued, studies would need to be conducted to evaluate these impacts. Evaluation of this operational modification also did not consider modifications to Project components, such as the outlet works, that may require modifications to accommodate higher regulated releases on a more frequent basis. It is also likely that modifications would need to be made to the existing DRS as part of this option.

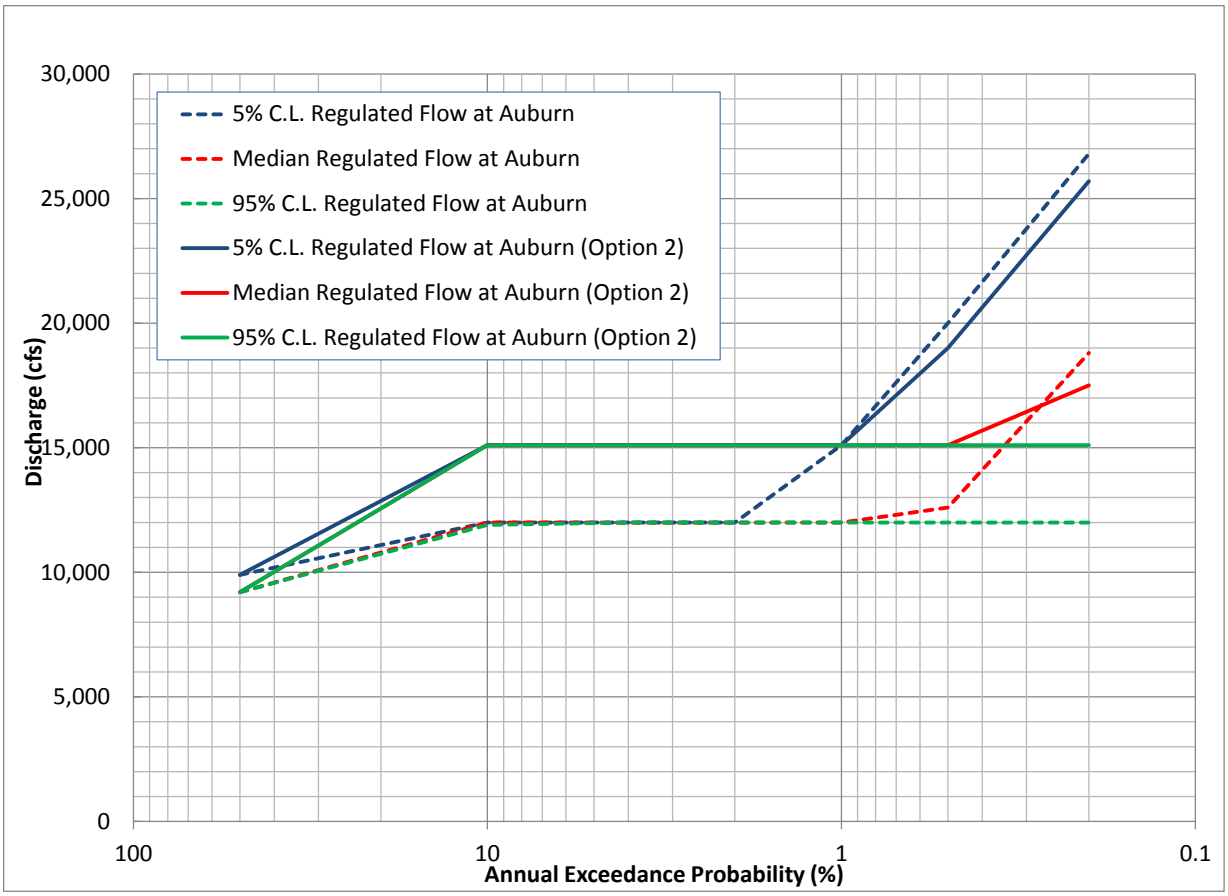



**Figure 4-2: Discharge vs Annual Exceedance Probability & Flood Frequency at Auburn for Option 2**

### 4.1.3. Option 3 (Structural Change)

For Option 3, the reservoir operation model was used as a tool to determine the *minimum* full pool elevation required for HHD to fully regulate the 0.2% AEP Median flood event. The model was run assuming that HHD releases are regulated to control flows at Auburn to the 10,000 cfs target flow on the rising limb of the flood hydrograph. Once the local inflow hydrograph peaked, the HHD releases were regulated to control flows at Auburn to the 12,000 cfs target flow as the flood control volume in the reservoir was evacuated. Figure 4-3 shows the reservoir operation model results.

As seen in this figure, the theoretical flow at Auburn is constant at 10,000 cfs until after the local inflow hydrograph has peaked, at which point the theoretical flow at Auburn is constant at 12,000 cfs. As a result of this hypothetical reservoir operation model run, the HHD reservoir elevation peaked at elevation of 1224.5 feet, which is approximately four feet below the lowest top of dam elevation (see Figure 1-1). For Option 3, this 1224.5 foot elevation represents the *minimum* required full pool elevation for HHD to be able to regulate the 0.2% AEP Median flood event to the 12,000 cfs target flow at Auburn. The actual required full pool elevation would be much higher than this. This is because HHD uses a DRS to prevent premature filling of the reservoir to the full pool elevation. In order to regulate the 0.2% AEP median flood event to the 12,000 cfs target flow rate, the full pool elevation would have to be sufficiently high in order to prevent the need for the DRS.

Some perspective on how much higher the full pool elevation may have to be above this minimum value, so as to prevent the need for the DRS, can be obtained from the results of the existing condition

operation of HHD as summarized in USACE (2012). During the 0.2% AEP Median flood event, the need for the DRS was initiated when the reservoir elevation reached approximately elevation 1150 feet NGVD29. This elevation is 56 feet below the existing condition full pool elevation and represents a condition where there is approximately 73,000 acre-feet of flood control volume remaining. These results suggest that the full pool elevation required to fully regulate the 0.2% AEP Median flood event would be substantially higher than the estimated 1224.5 foot minimum elevation. It may be on the order of 50 feet higher. More likely however, the required elevation would be that which would provide approximately 73,000 acre-feet of flood control volume above elevation 1224.5 feet NGVD29. These are only estimates, and it is re-emphasized that a more rigorous analysis, including development of a DRS that corresponds with the dam raise, would be required to determine the actual full pool elevation required to fully regulate the 0.2% AEP Median flood event.

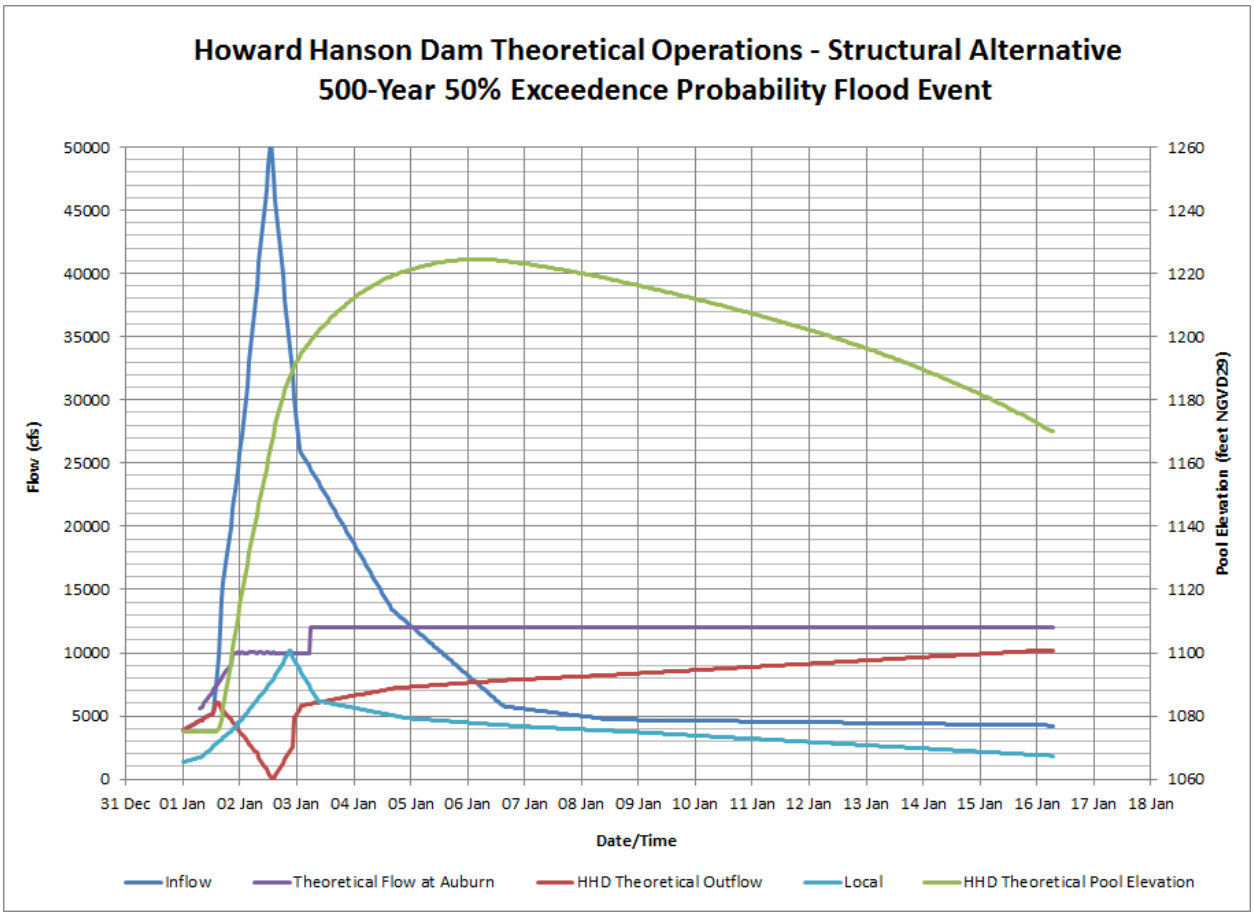



**Figure 4-3: HHD Operations Model Results for 0.2% AEP Median Flood Event, Structural Alternative**

## 4.2. Policy and Implementation Considerations

The following sections summarize the policy and implementation considerations for potential operational or structural modifications to HHD.

### 4.2.1. Operational Modifications

Options 1 and 2 would involve changes to the operating parameters established in the Water Control Manual for Howard Hanson Dam.

Option 1 evaluates increasing releases from the dam during the initial portion of the flood event (i.e. the rising limb of the flood hydrograph), from current maximum of 10,000 cfs to 12,000 cfs. Since this option would not increase maximum flow rates downstream of the dam, beyond those currently experienced, it is anticipated that this option would require limited additional studies to support changes to the Water Control Manual and in accordance with the Federal Rules Making Process.

Option 2 evaluates increasing the regulated releases during both the rising (target flow of 13,100 cfs) and receding (target flow of 15,100 cfs) limbs of the flood hydrograph. While changing the maximum release does not modify the authorized purpose of the dam, and therefore does not appear to require congress to authorize a change to the Project, it would require an analysis of the impacts (both hydraulic and environmental) on the Green River below the dam. Option 2 would also require engineering feasibility studies related to components of the dam such as the outlet works to support higher regulated releases.

Both Operational options would result in a change to the water control manual and would likely be considered a federal action, and therefore trigger the NEPA process and also require consultation under Section 7 of the Endangered Species Act and Section 106 consultation and potentially tribal consultation regarding treaty usual and accustomed fishing rights

#### 4.2.1.1. Authority

Authority for the USACE to conduct and fund the required engineering and environmental studies, and to fund required engineering design and construction to address downstream impacts from the increased maximum releases, could potentially be conducted through the "Continuing Authorities Program" (CAP). CAP is a specific group of 10 legislative authorities under which the Secretary of the Army, acting through the Chief of Engineers, is authorized to plan, design, and implement certain types of water resources projects without additional project specific congressional authorization. In this instance the specific CAP authority would be for Flood Control under Section 205 of the Flood Control Act of 1948, as amended. IAW USACE Engineering Regulation 1105-2-100, "Planning Guidance Notebook":

> *"CAP authorities may be used to provide additional improvements to a completed portion of a specifically authorized project so long as they do not impair or substantially change the purposes or functions of the specifically authorized project."*[1]

The Section 1135 project implemented in 1996 for low flow augmentation is an example of a CAP project. While use of the CAP program does not require Federal Authorization, excluding the project authorization steps described for Option 3, the steps of the CAP process are similar, although lower in total cost. For instance:

- During the Feasibility Phase up to $100,000 in studies can be 100% Federally Funded. Additional costs are split equally (50%/50%) with the local sponsor.[2]
- Total cost for an individual CAP, Section 205 project cannot exceed $7 million and total USACE expenditures, in a single fiscal year, for Section 205 projects cannot exceed $50 million.[3]

[1] USACE Engineering Regulation 1102-5-100, dated 22 April 2000, *Planning Guidance Notebook,* page F-5
[2] USACE Engineering Regulation 1102-5-100, dated 22 April 2000, *Planning Guidance Notebook,* page F-9

- Costs for preparation of plans and specifications and construction are shared at a minimum of 65% federal/35% non-federal and up to a maximum of 50%/50%.[4]

In order to initiate a CAP project a non-federal sponsor submits a letter to the Corps requesting assistance. Federal funding under this program is competitive nationally and requests typically exceed the program funding appropriation authorized by congress each year. Environmental compliance and consultation would typically be initiated during the feasibility and completed during final design. Changes to the Water Control Manual, for either Option 1 or 2 (after completion of the CAP process), must be made through the application of the "Federal Rules Making Process" and are highlighted below:

1. In the case of a modification to an existing rule, the process formally begins with the publication of an "Advanced Notice of Proposed Rule Making" being published in the Federal Register. The Advance Notice is a formal invitation for interested parties to participate in shaping the proposed rule and starts the notice-and-comment process in motion. Normally 60 days is allowed for public comment and in many cases includes face-to-face meetings with appropriate parties.
2. Based on the comments received, an initial modification to the existing rule will be developed over a period of approximately 30 days.
3. This draft rule is then once again published in the Federal Register, with an additional 60 day comment period.
4. Again, modifications are made to the proposed change of the dam's operating rules over another roughly 30 day period.
5. The final amended rule is then published in the Federal Registry to specify the final procedures for the public.

The optimal timeline described above provides for a 180 day period, but delays often push the total process timeline well beyond 1 year. In fact a 2009 Government Accounting Office (GAO) study determined the average rule making process took approximately 4 years.[5]

### 4.2.2. Structural Modification

Option 3 involves structural modifications to HHD that would necessitate changes to the existing Project. Authority to modify an existing authorized project is provided under the provisions of Section 216 of the Flood Control Act of 1970. The AWSP authorized in 1999, and partially implemented, is an example of a modification conducted under Section 216. The initial step begins with the U.S. Army Corps of Engineers (USACE), Seattle District receiving a request from a potential local sponsor for assistance. Once received, USACE will conduct a preliminary assessment of the potential "need" for the project to determine if there is a potential federal interest in developing the project using existing Operation and Maintenance (O&M) funds for the Dam. Alternatively, the local sponsor may conduct the preliminary investigation and receive credit against future funding obligations for "in-Kind Service" provided.

If the preliminary investigation concludes the project warrants further investigation, it then starts the journey through the Federal authorization, investigation, and design and construction process. USACE

[3] USACE Engineering Regulation 1102-5-100, dated 22 April 2000, *Planning Guidance Notebook,* page F-11
[4] http://www.nae.usace.army.mil/Missions/PublicServices/ContinuingAuthoritiesProgram/Section205.aspx
[5] GAO Report to the Chairman, Committee on Oversight and Government Reform, House of Representatives, *"Federal Rulemaking, Improvements Needed to Monitoring and Evaluation of Rules Developed as Well as to the Transparency of OMB Regulatory Reviews*," April 2009, page 5

implementing guidance is codified in Engineering Regulation 1105-2-100, "Planning Guidance Notebook." The process for authorizing the modification involves several distinct steps:

1. The initial step begins with the U.S. Army Corps of Engineers (USACE), Seattle District receiving authorization to study the potential benefits of modifying the dam. The authorization may be a resolution from the U.S. House Committee on Public Works and Transportation, a resolution from the U.S. Senate Committee on the Environment and Public Works, or by inclusion in a public law.
2. Once the authorization, often referred to as a "new start" is made, the project will enter the Reconnaissance Phase. Some changes to the Reconnaissance Phase were included in the recently authorized Water Resource Development Act (WRDA 2014) and implementation guidance will be forthcoming over the next several years. The current objectives of the Reconnaissance Phase and process is outlined below::
    a. determine if the water resource(s) problems warrant Federal participation in feasibility studies,
    b. define the Federal interest,
    c. complete a 905(b) Analysis (refers to Section 905(b) of the WRDA of 1986) or a Reconnaissance Report,
    d. prepare a Project Management Plan (PMP),
    e. assess the level of interest and support from non-Federal entities, and
    f. negotiate and execute a Feasibility Cost Sharing Agreement (FCSA).

    The reconnaissance phase is fully funded by the Federal government (approximately $150,000), but cannot begin until funds are appropriated as part of the annual federal appropriations funding of USACE activities. Once funding is received, the target for completion of the Reconnaissance Phase is 6 to 12 months from initial obligation of reconnaissance funds to a signed FCSA. A successful reconnaissance phase results in a report confirming a Federal interest, a preliminary determination that the benefits of constructing the project exceed the costs to complete the project, and identification of a local project sponsor willing to provide the required non-federal funds for subsequent phases of the project.
3. If the Reconnaissance Report deems further investigation is warranted, the project can proceed to conduct a feasibility study. The objective of feasibility studies is to investigate and recommend solutions to water resources problems. The results of these studies are documented in a feasibility report that includes documentation of environmental compliance. The cost of feasibility studies, are 50 percent Federal and 50 percent non-Federal as defined in Section 105 of the WRDA of 1986. Like the reconnaissance phase, funding for a feasibility study must be provided by appropriation, normally in the fiscal year following completion of the reconnaissance report. In the past the time to complete the feasibility study could take several years. For instance, The Seattle District received authorization to start the Feasibility Study for the Howard Hanson Dam "Additional Water Storage Project" in 1989 and the Final Feasibility Study Report was not completed until 1998.[6] Efforts by USACE Headquarters to streamline the feasibility process were codified in2012 with a goal that new studies should be completed in 18-36 months, and are intended to have a maximum cost of $3 million[7] divided equally between the Federal government and the local project sponsor.

[6]http://www.nws.usace.army.mil/Portals/27/docs/civilworks/projects/Final%20HHD%20AWSP%20Feasibility%20Report%20and%20EIS%20August%201998.pdf

[7] USACE Memorandum for Major Subordinate Commands, dated 8 Feb., 2012, SUBJECT: U.S. Army Corps of Engineers Civil Works Feasibility Study Program Execution and Delivery

4. If the results of the Seattle District's Feasibility Study continue to support Federal involvement, the report is forwarded first for review by the Northwest Division. Projects of this scale also require an independent external peer review (IEPR) process outside of the Corps of Engineers. Once these reviews are complete and comments satisfactorily addressed the report is sent on to the Civil Works Review Board at USACE Headquarters. An endorsement of the project's public benefits and a recommendation for project authorization is provided in the form of a signed Chief of Engineer's Report. Time to complete the Division and USACE HQ reviews is included in the 18 to 36 months described in Item #3 above.
5. The next step is Federal authorization for the project. Project authorization is provided by Congress through the Water Resources Reform and Development Act (WRRDA), formally the Water Resources Development Act (WRDA). Recent WRRDA/WRDA bills were passed into law in 2014, 2007, and 2000, a recent average of 7 years between bills.
6. After authorization in a WRRDA, funds may be appropriated to begin the Preconstruction Engineering and Design (PED) Phase. As with the Feasibility Phase, PED Phase funding is provided in USACE's annual budget through the energy and water bill. In the PED Phase, 25% of the cost must be provided by the local project sponsor.[8] While PED funding for changing the Dam's operation beyond its currently authorized levels may be possible in one year, securing all necessary Federal PED funds for the design effort to modify the dam may result in funding being spread over more than one Federal Fiscal Year. As an example, the 1998 cost estimate to complete the PED for the Howard Hanson Dam "Additional Water Storage Project" was $8.34 million dollars.[9]
7. Once the PED Phase is complete, including final engineering designs, construction cost funding can be determined and construction funding can be appropriated. Securing all necessary Federal Construction funds may also result in funding being spread over more than one Federal Fiscal Year.

Mandated local sponsor contributions, for the overall project, range between 35% (minimum) and 50% (maximum). The range is based on the costs to secure necessary Lands, Easements, Rights-of-way, Relocations and Disposal Areas (LERRD) for the project, which are 100% the responsibility of the local sponsor.[10]

Design requirements are beyond the scope of this preliminary analysis. However a structural modification to increase the height of the dam would likely require modifications to the entire embankment prism. The existing drainage tunnel, seepage issues and outlet works would also require engineering studies and modifications. An increase in the dam height would also necessitate changes to the spillway gates and debris booms in the reservoir, which were recently upgraded to improve the safety of the dam during probable maximum floods. The existing railroad would also likely require relocation. A raise to the dam structure would also require geotechnical studies of the surrounding area to identify and address potential concerns. Potential impacts limitations to flood operation during implementation would also need to be considered during engineering studies. Dam Safety modifications implemented between 2010 and 2014 would also need to be revisited with an increased full pool elevation. For example geotechnical concerns related to the right abutment were not eliminated, but instead satisfactorily addressed to the current pool elevation of 1206'.

[8] USACE Engineering Regulation 1102-5-100, dated 22 April 2000, *Planning Guidance Notebook,* page. 2-17
[9] http://www.nws.usace.army.mil/Portals/27/docs/civilworks/projects/Appendix%20C%20Cost%20Estimate.pdf
[10] Ibid. page E-128

Modifications of this magnitude would also require extensive environmental studies to assess impacts. Similar to operational changes the federal action would also trigger the NEPA process and require consultation under Section 7 of the Endangered Species Act and Section 106 consultation and tribal consultation regarding treaty usual and accustomed fishing rights. A secondary potential benefit associated with a pool raise would be the opportunity to include additional low flow augmentation during the summer months.

Potential costs for Option 3 cannot be provided without at least some preliminary engineering design upon which to base the costs, but some awareness of an "order of magnitude" approximation can be obtained based on the cost for recent modifications at Howard Hanson Dam and similar projects throughout the United States. Cost for these projects range from a low of $21 million, with a corresponding local 35% cost share of $7.35 million, to a high cost of $462 million, with a 35% local cost share of $161 million (see below).

1. Recent activities at Howard Hanson Dam have included both:
    a. The completion of a seepage barrier (grout curtain) and drainage improvements to the right abutment totaling $40 million.
    b. Proposed downstream fish passage facilities are currently scheduled to be constructed in 2018.[11] In 2009, the estimated cost for the passage feature was $200 million.[12]
    c. Both of these features would have to be modified, assuming studies to support Option 3 are not completed in time to delay the current timeline for construction of the currently scheduled fish pass facilities. If modifications to the dam are equal in cost to the recent and current improvement costs, the local sponsor contribution would be at least $84 million (($40 M + $200 M)*35%)
2. USACE New York, Waterbury Dam VT 2001 construction contract for $21M to address seepage and Settlement in the embankment,[13] with a local cost share of $7.35 million.
3. Likewise recent construction over the past 3 years, by the Jacksonville District associated with repairs to the Herbert Hoover Dam and Levee system have exceeded $462 M, with significant work left to be completed.[14] 35% of $462 M would be $161 M.
4. One of the recent dams constructed by USACE was the Seven Oaks Dam in California. Construction of the dam was completed in 2000, at a cost of $450 M,[15] with a minimum local cost share of $157.5 M.

Table 4-2 below, demonstrates a possible timeline to complete a project requiring construction modifications to the dam. The potential time required ranges from 7 to 14 years, depending on the sequence of congressional action. This timeline also assumes no delays in receipt of federal funding for the different phases and that all environmental compliance and consultation can be accomplished in a timely manner such that authorization and funding for PED is not delayed.

[11] http://www.mytpu.org/tacomawater/water-source/green-river-watershed/howard-hanson-dam.htm
[12] http://www.kentreporter.com/news/51267057.html
[13] http://www.nan.usace.army.mil/Media/FactSheets/FactSheetArticleView/tabid/11241/Article/8321/fact-sheet-waterbury-dam-waterbury.aspx
[14] http://riverscoalition.org/wp-content/uploads/2014/03/Lt-Col-Greco-RC-presentation-3-26-14.pdf
[15] http://www.sbcounty.gov/dpw/floodcontrol/sevenOaks.asp

**Table 4-2: Construction Modification Timeline**

| Action\Project Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Congress Authorizes Project Study | | | | | | | | | | | | | | | |
| Congress Appropriates Recon Funds | | | | | | | | | | | | | | | |
| USACE Conducts Reconnaissance Study | | | | | | | | | | | | | | | |
| Congress Appropriates Feasibility Funds | | | | | | | | | | | | | | | |
| USACE Conducts Feasibility Study | | | | | | | | | | | | | | | |
| Congress Passes WRRDA | | | | | | | | | | | | | | | |
| Congress Appropriates PED Funds | | | | | | | | | | | | | | | |
| USACE Prepares PED Documents | | | | | | | | | | | | | | | |
| Congress Appropriates Construction Funds | | | | | | | | | | | | | | | |
| USACE Constructs the Project | | | | | | | | | | | | | | | |

Construction timelines vary greatly among projects, based primarily upon two factors: appropriation of all required construction funds and the project construction schedule, once all funding is secured. For planning purposes, construction projects requiring over $600 million, will most likely exceed 3 years for construction.[16] Therefore it is reasonable to assume construction projects, totaling under $600 million should be completed in three years or less, but this is not a hard and fast rule. For comparison, the Seattle District's Green River Ecosystem Restoration Project, authorized by WRDA 2000, with a currently estimated total implementation cost of $195 million had elements under construction in 2005 and is not yet complete.[17]. Similarly, implementation of the AWSP has also exceeded three years.

## 4.3. Findings

The preliminary analysis of the three options finds that there are potential opportunities to provide additional flood risk management benefits for the Lower Green River. Of the two operational changes, Option 2 provides the greatest potential benefit. However the potential benefits of Option 2 must be weighed against the impacts of increased flows below HHD and the study time and costs associated with pursuing such changes. As noted in Section 3, if operational changes were to be pursued, a range of different operation scenarios could be considered. Further, operational changes could be assessed independent of or in combination with levee modifications in the Lower Green River aimed at increasing the level of protection afforded by the levee system. Option 3 has the potential to provide the greatest increase in levels of protection downstream but would have the most significant study, impact and implementation costs. Option 3 would also have the longest timeframe and the greatest uncertainty in achieving actual implementation given uncertainties in funding, authorization, and satisfactorily completing necessary engineering and environmental studies. Approval of the SWIF can also not be dependent on federal authorization (Option 3) or funding (Option 2 if pursued under the CAP authority).

The following table summarizes the potential benefit of each option along with a summary of challenges and complexity that could ultimately affect the successful implementation of each option.

[16] US Army Corps of Engineers, Engineering and Construction Bulletin No. 2013-11, Issued 11 April 2013, Subject: USACE Mega-Project Management: Additional Project, Engineering and Construction Management Controls. Enclosure 2

[17] http://www.nws.usace.army.mil/Missions/CivilWorks/ProgramsandProjects/Projects/GreenDuwamishRiverEcosystemRestoration.aspx

**Table 4-3: Summary of Options**

| *Criteria and/or Potential to Impact Successful Project Implementation* | Option 1<br>Operational<br>(12,000 cfs on rising hydrograph) | Option 2<br>Operational<br>(target regulated flow to 15,100 cfs) | Option 3<br>Structural |
|---|---|---|---|
| **Relative Degree of Potential Benefit Related to flood operation** | Minimal | Minimal-Moderate | Very High |
| **Authority** | May be studied and Implemented under CAP. | May be studied and Implemented under CAP if costs to address downstream impacts are within CAP per project limit. | New authorization required. |
| **Funding** | Low justification for federal interest. | Moderately certain if perceived as high priority at the federal level and strong local support among stakeholders. | Given current federal funding climate, adequate and timely budget appropriations is uncertain. Current issues with the AWSP could also adversely affect funding likelihood. Initial studies could potentially be funded by non-federal interests. |
| **Engineering Studies & Complexity** | Minimal | Moderate | Extensive scope and very high complexity |
| **Dam Safety Issues** | None Apparent | None Apparent | Multiple |
| **Environmental Impacts Downstream** | Minimal | Impacts to Middle Green and higher flows on levees in Lower Green. | Impacts to Middle Green and higher flows on levees in Lower Green. |
| **Environmental Compliance, Consultation and Rule Making** | Moderate | Challenging | Very Challenging |

# 5. REFERENCES

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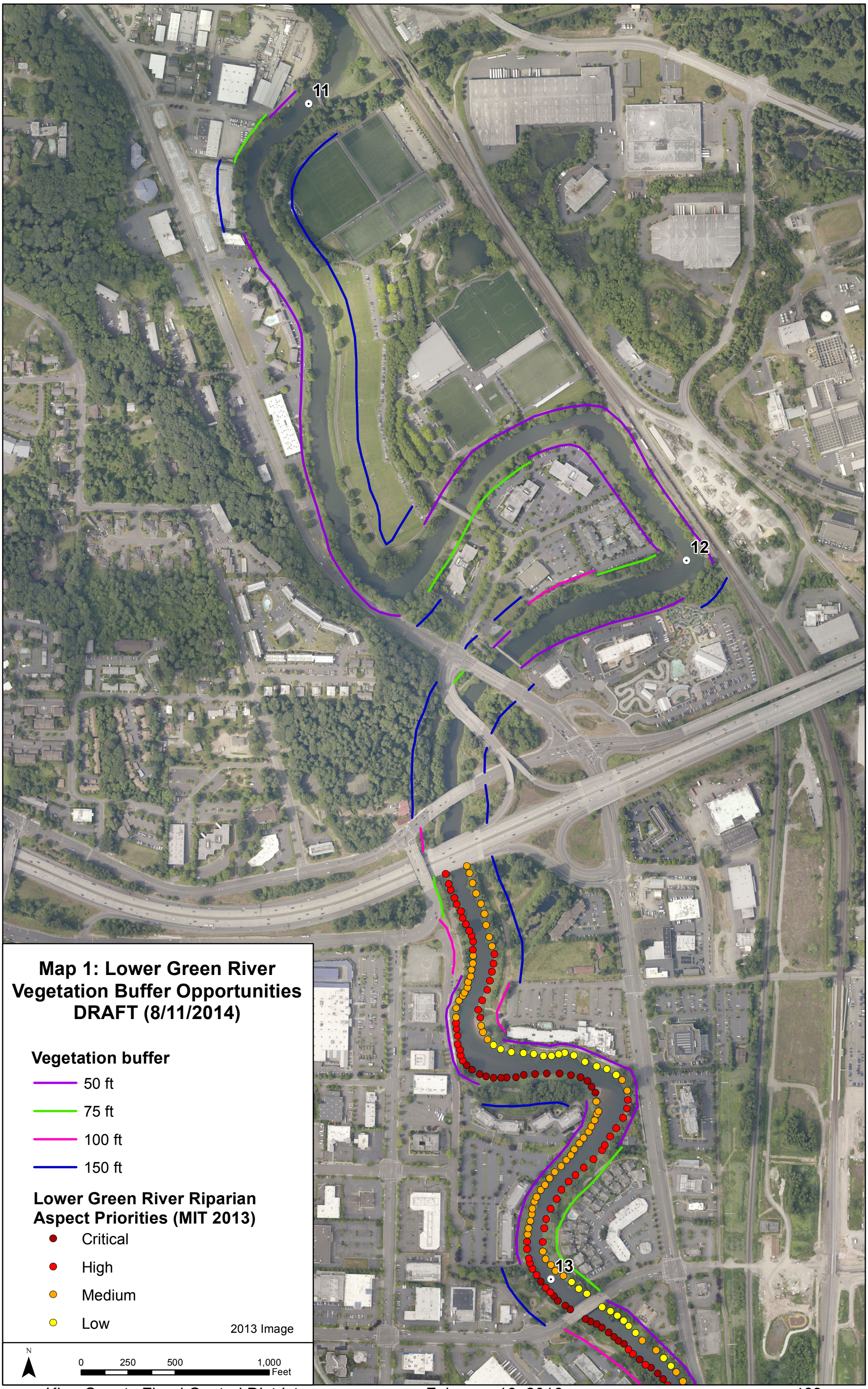
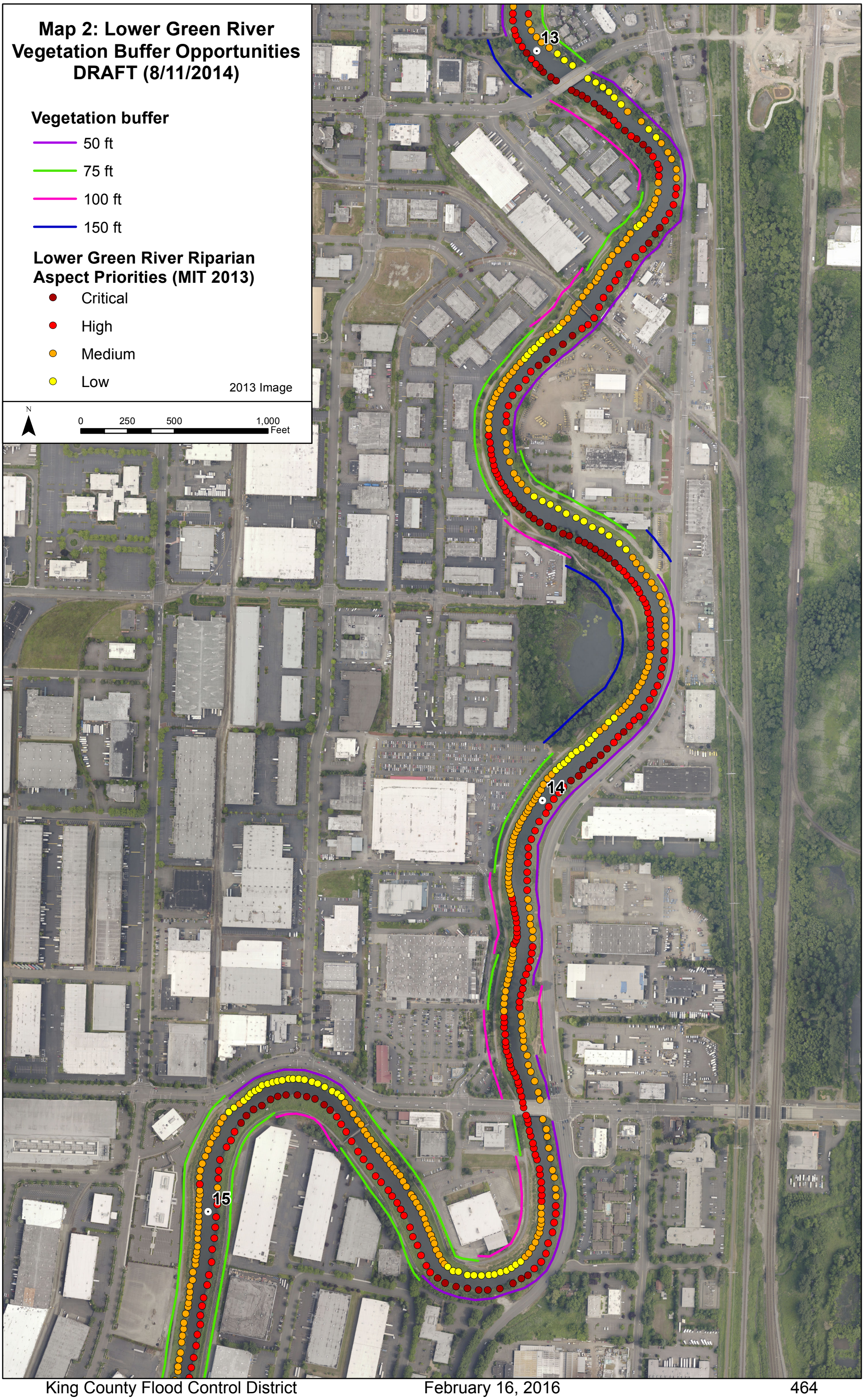
Tetra Tech/NHC. 2014. Green River System-Wide Improvement Framework Hydraulics Technical Memorandum. Attachment D to Draft Current Conditions Report. May 2014.


11
12
13
Map 1: Lower Green River
Vegetation Buffer Opportunities
DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian
Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet


Map 2: Lower Green River
Vegetation Buffer Opportunities
DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian
Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet
13
14
15

# Map 3: Lower Green River Vegetation Buffer Opportunities DRAFT (8/11/2014)

**Vegetation buffer**

- 50 ft
- 75 ft
- 100 ft
- 150 ft

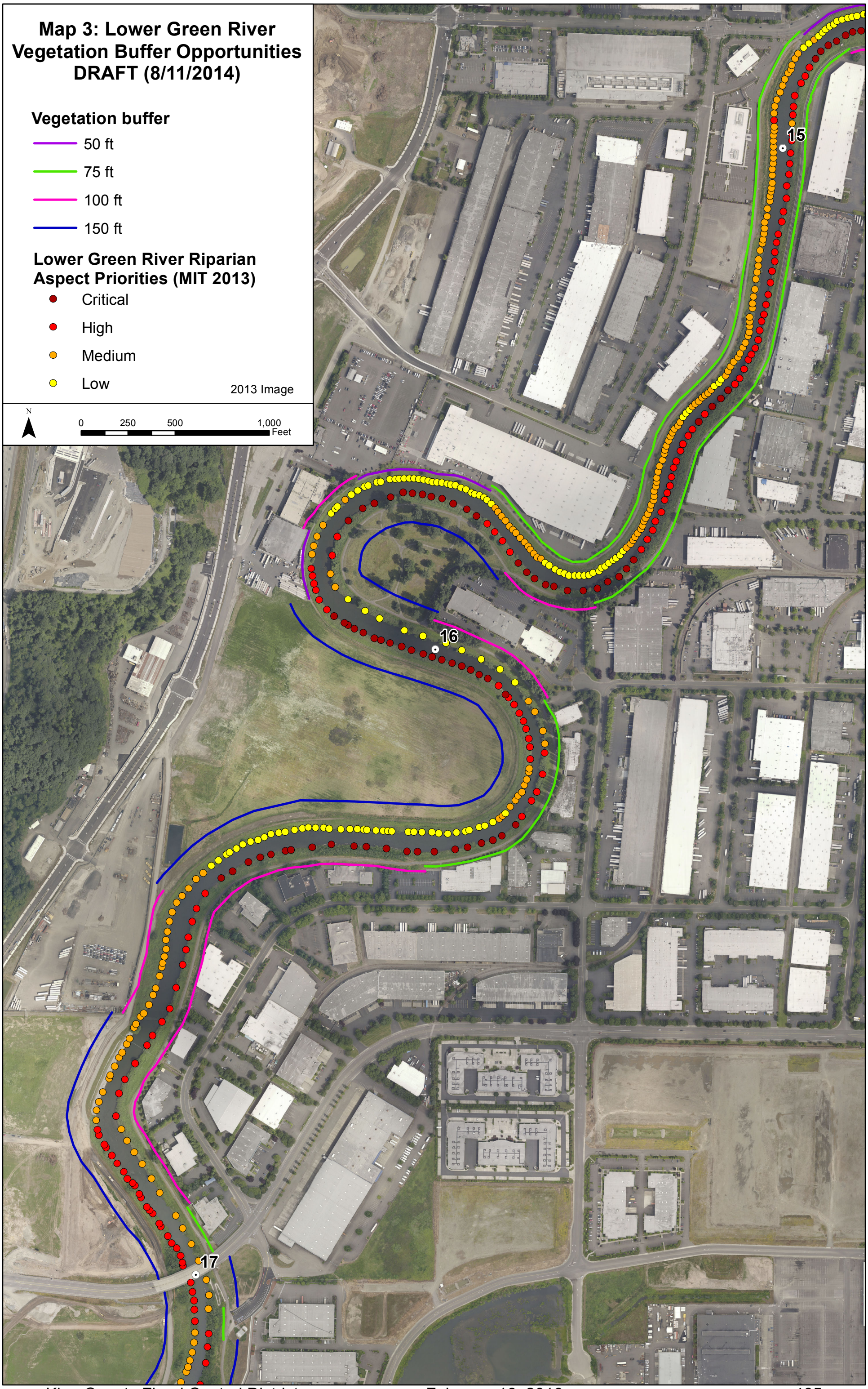
**Lower Green River Riparian Aspect Priorities (MIT 2013)**

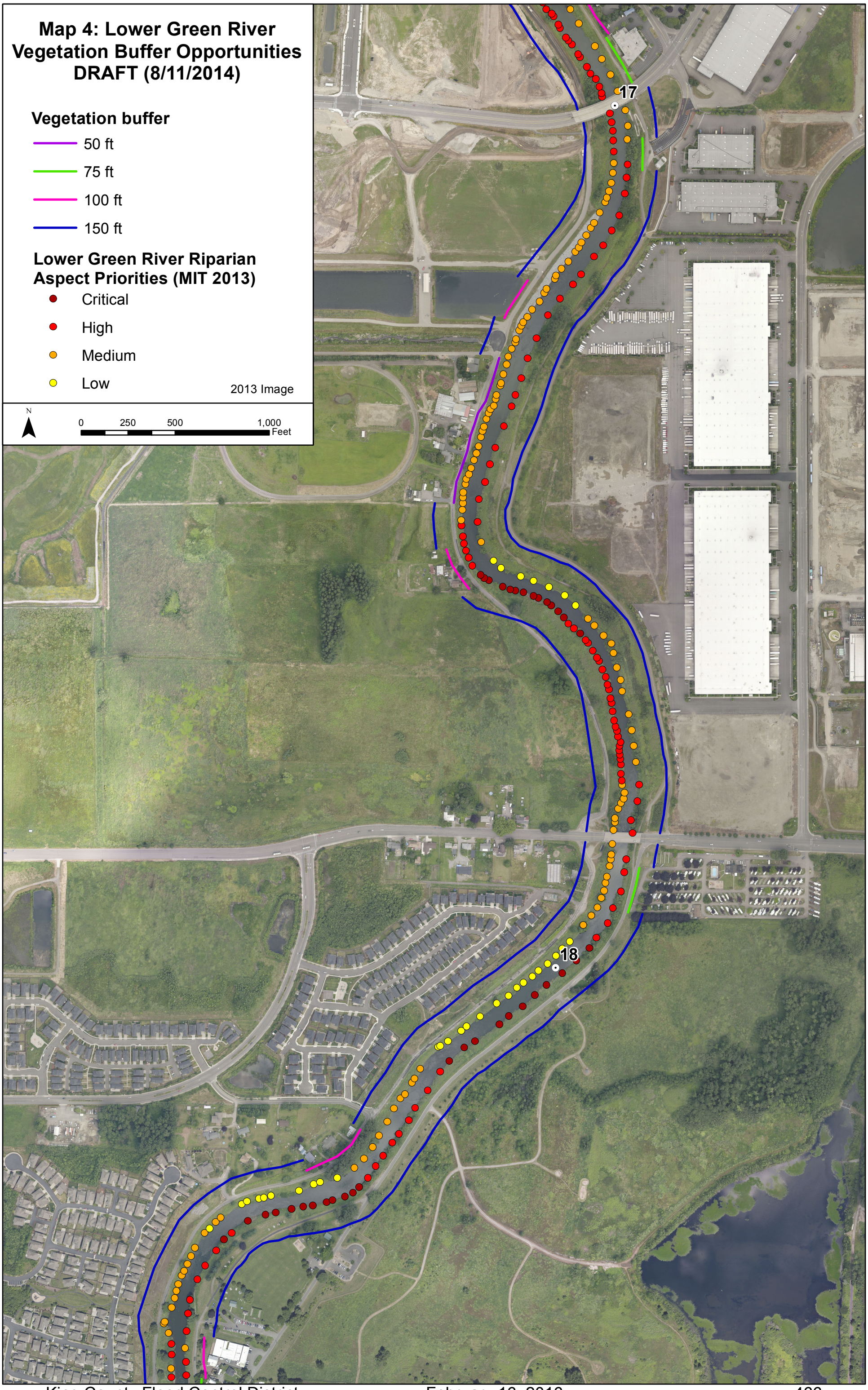
- Critical
- High
- Medium
- Low

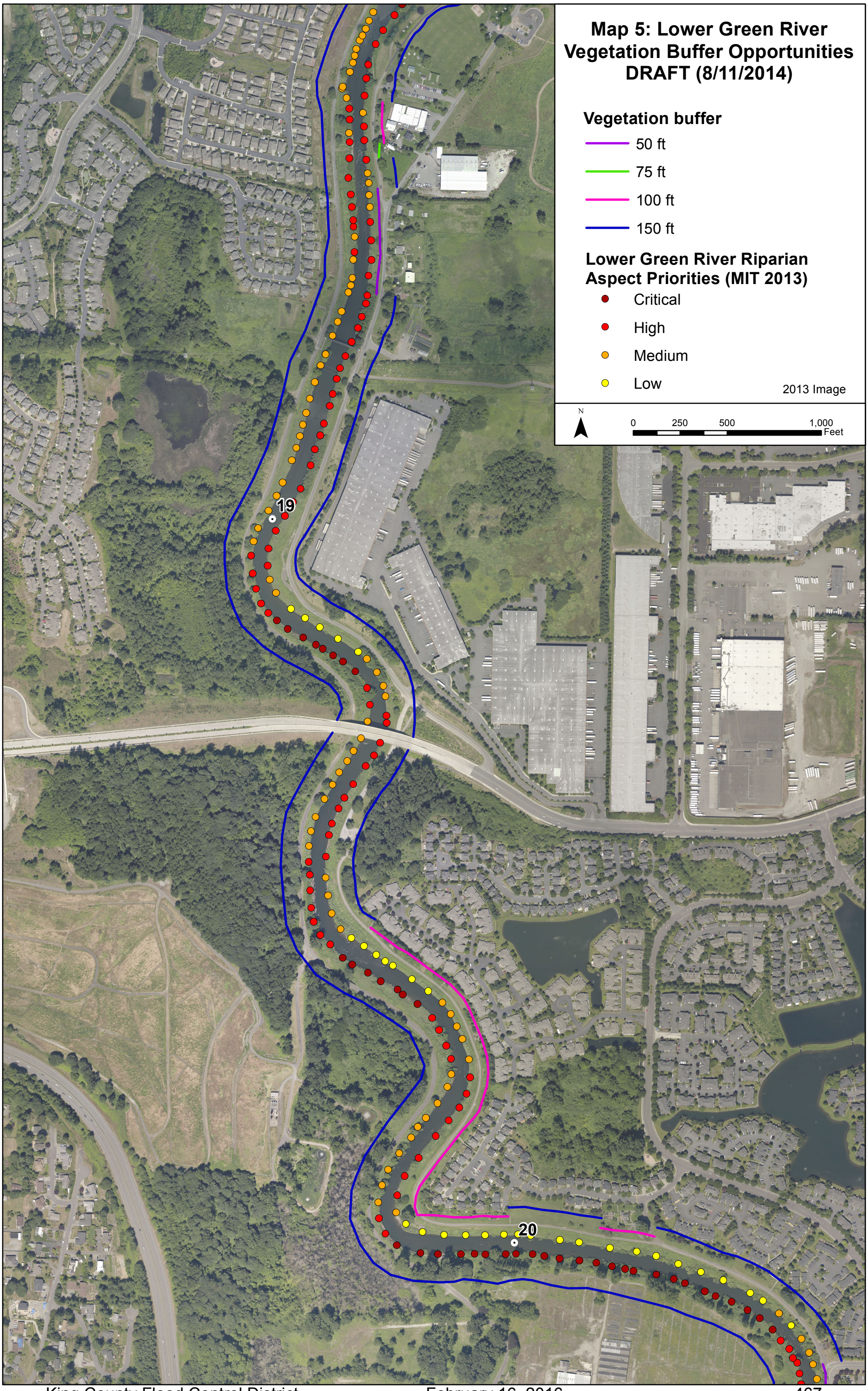
2013 Image

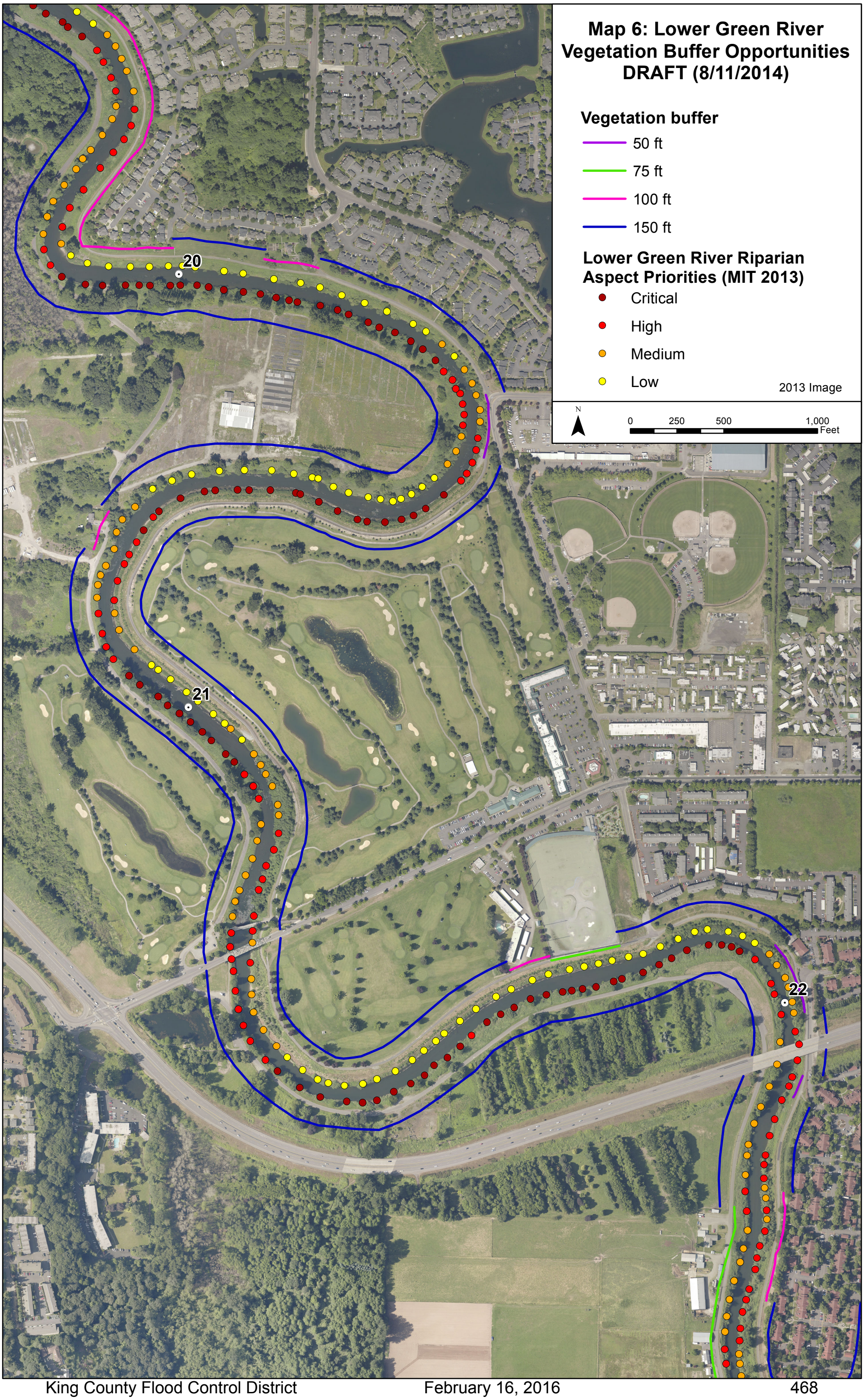
N

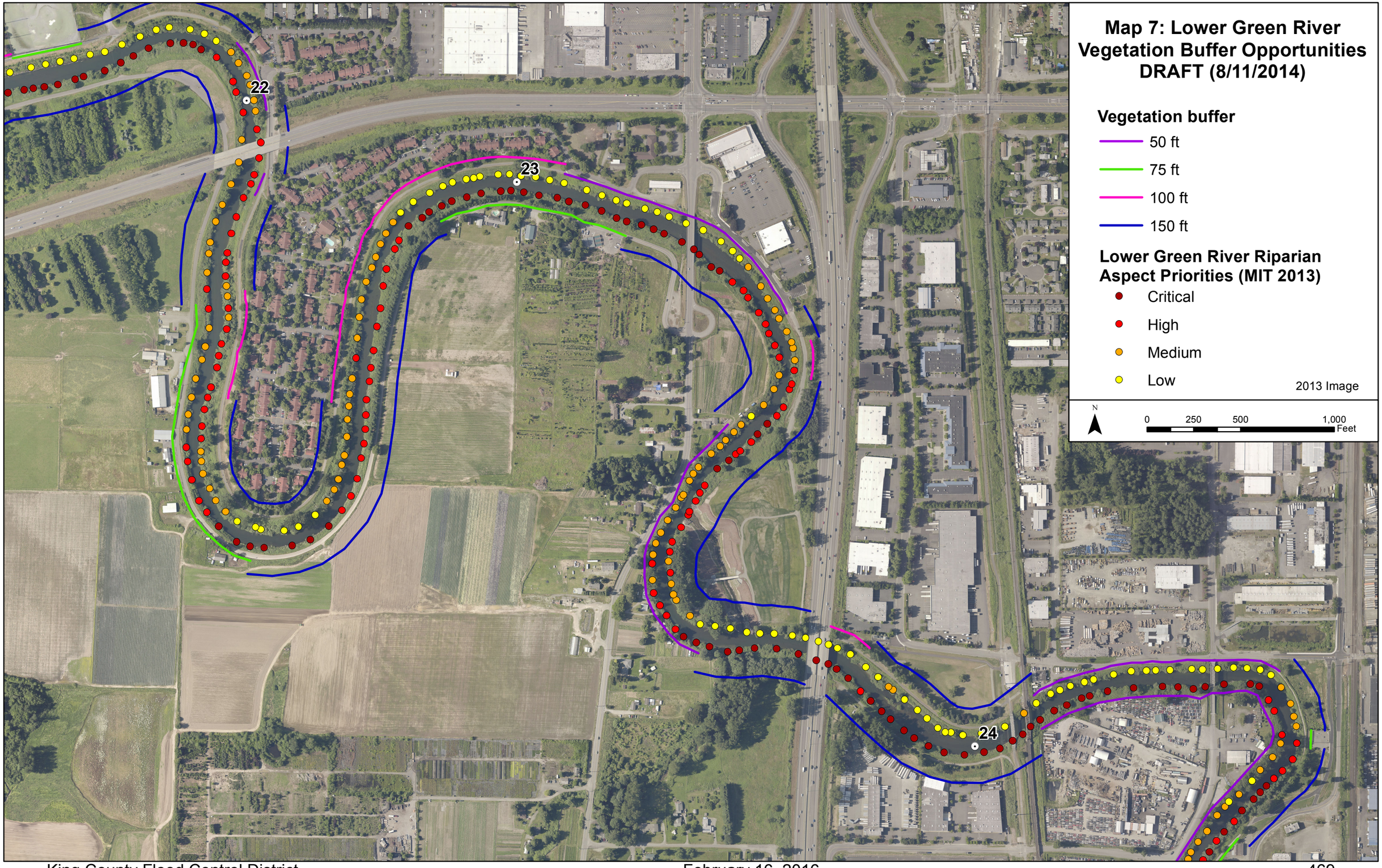
0 250 500 1,000 Feet

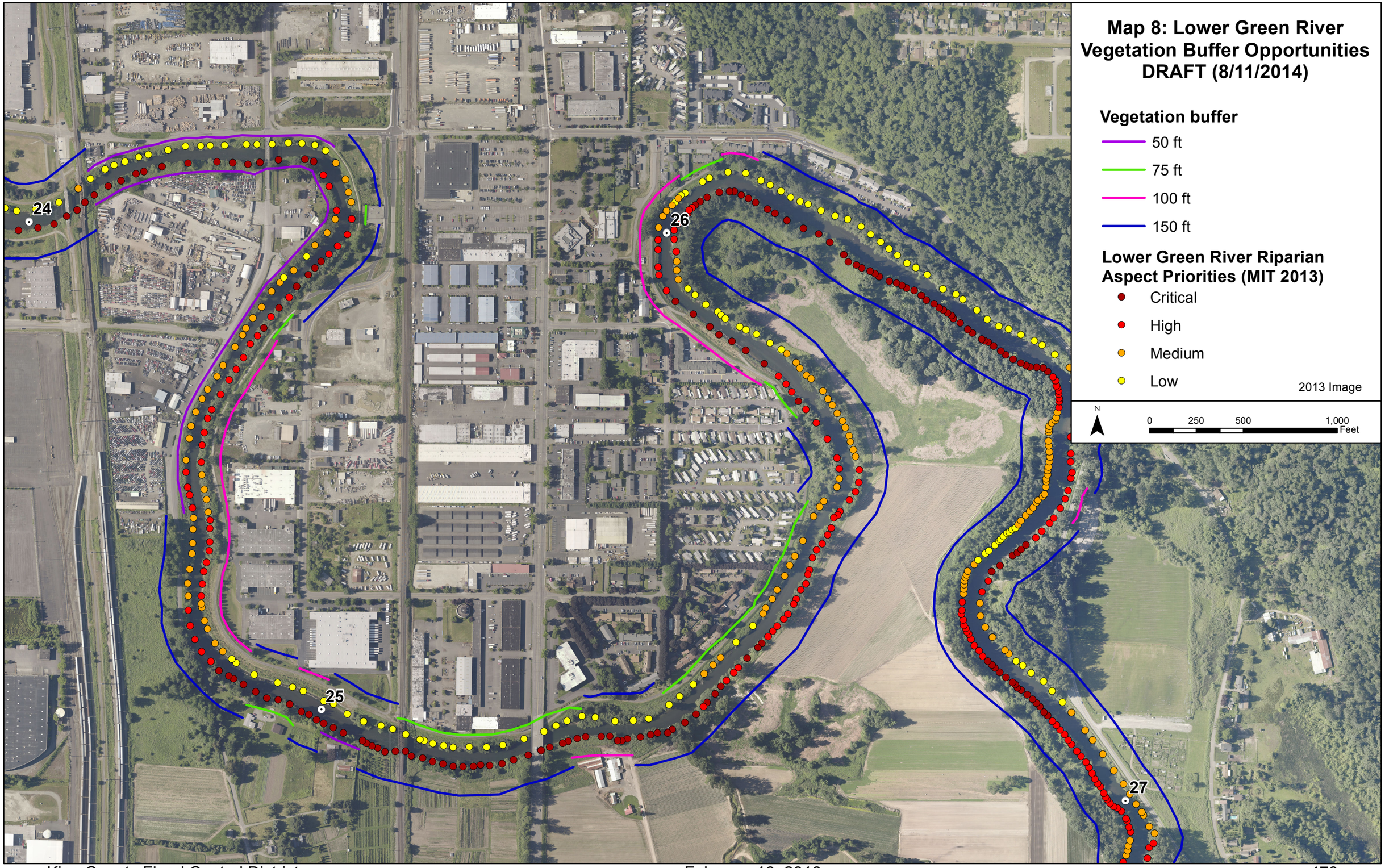


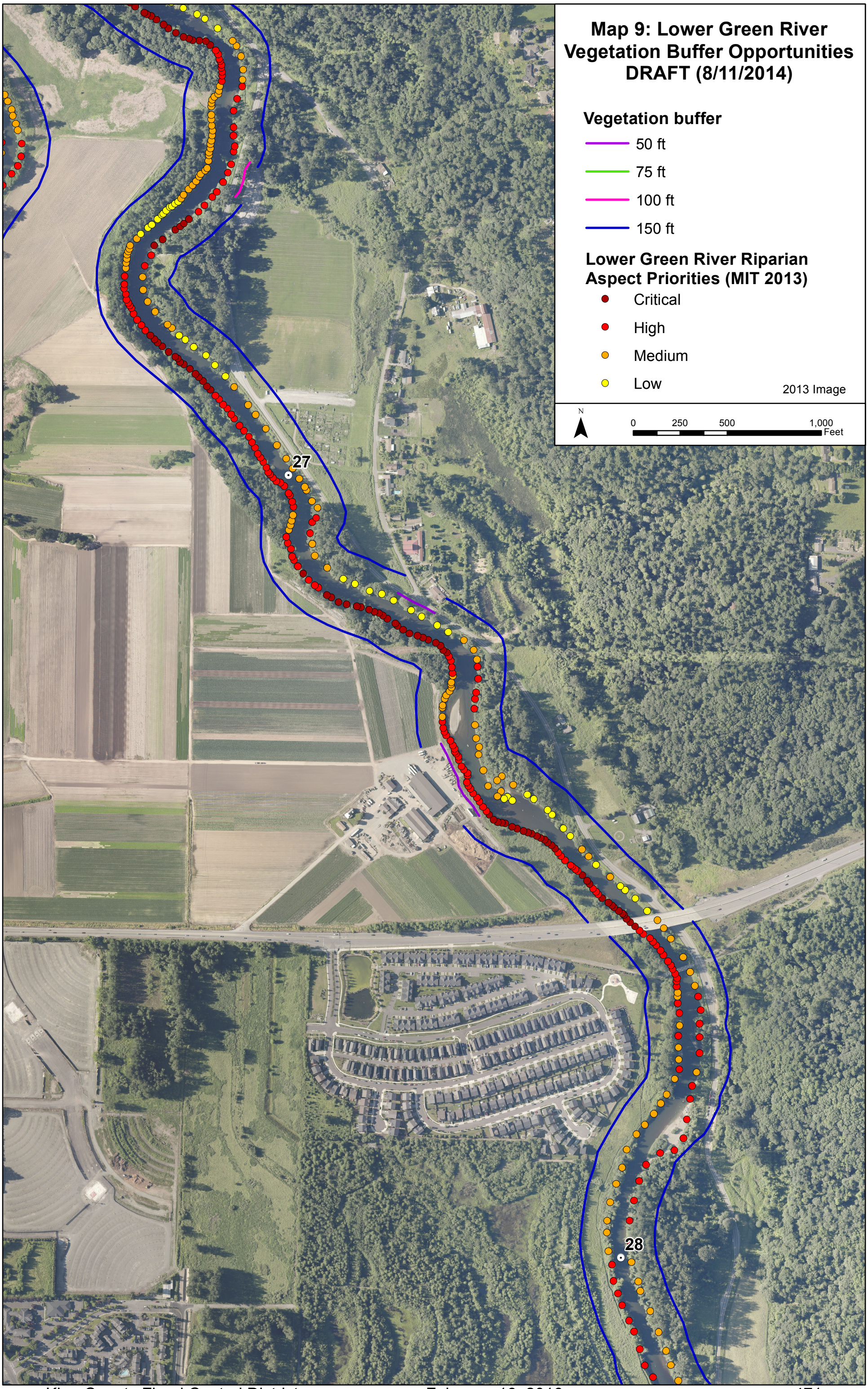

Map 4: Lower Green River
Vegetation Buffer Opportunities
DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian
Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet
17
18

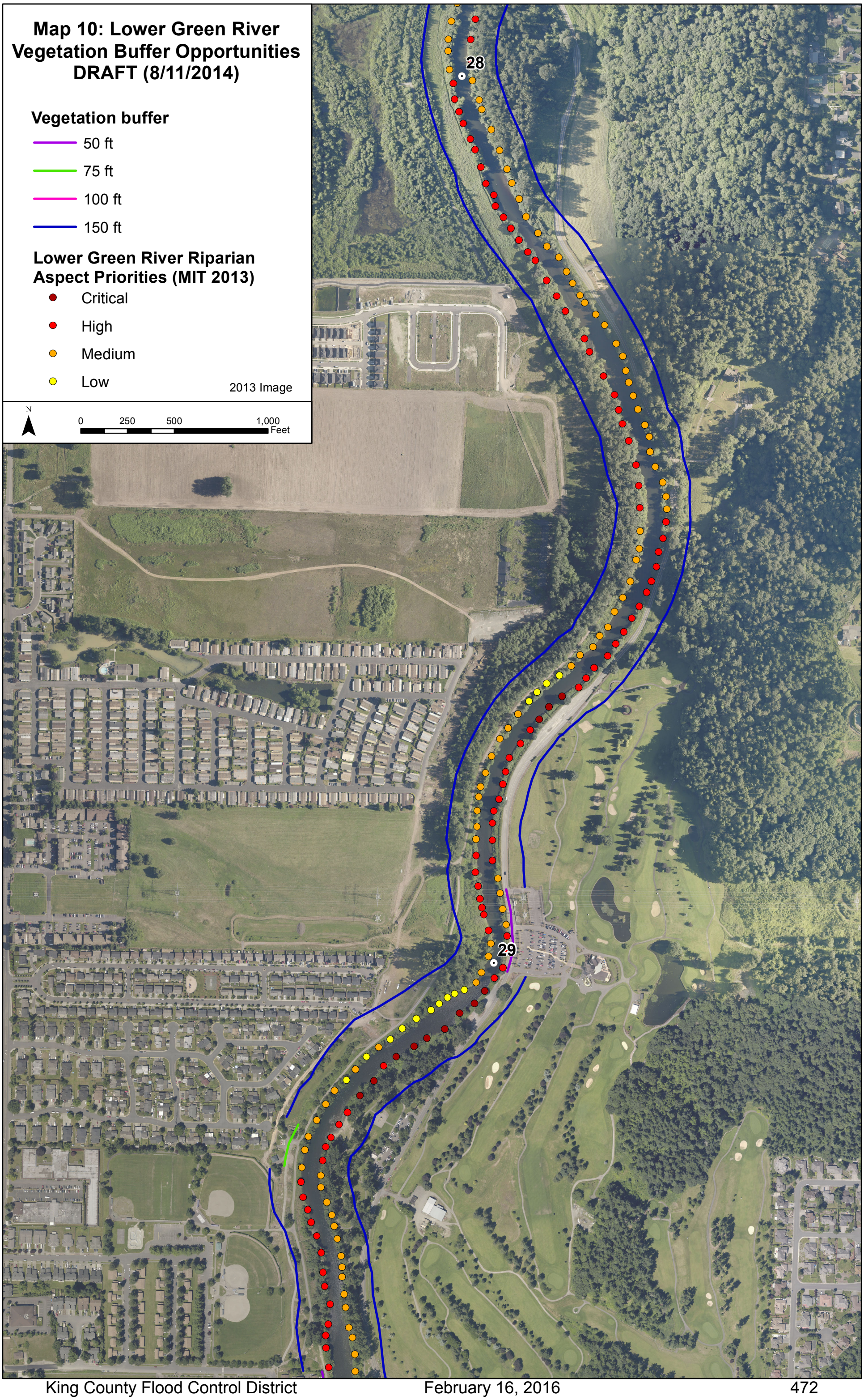

Map 5: Lower Green River
Vegetation Buffer Opportunities
DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian
Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet
19
20

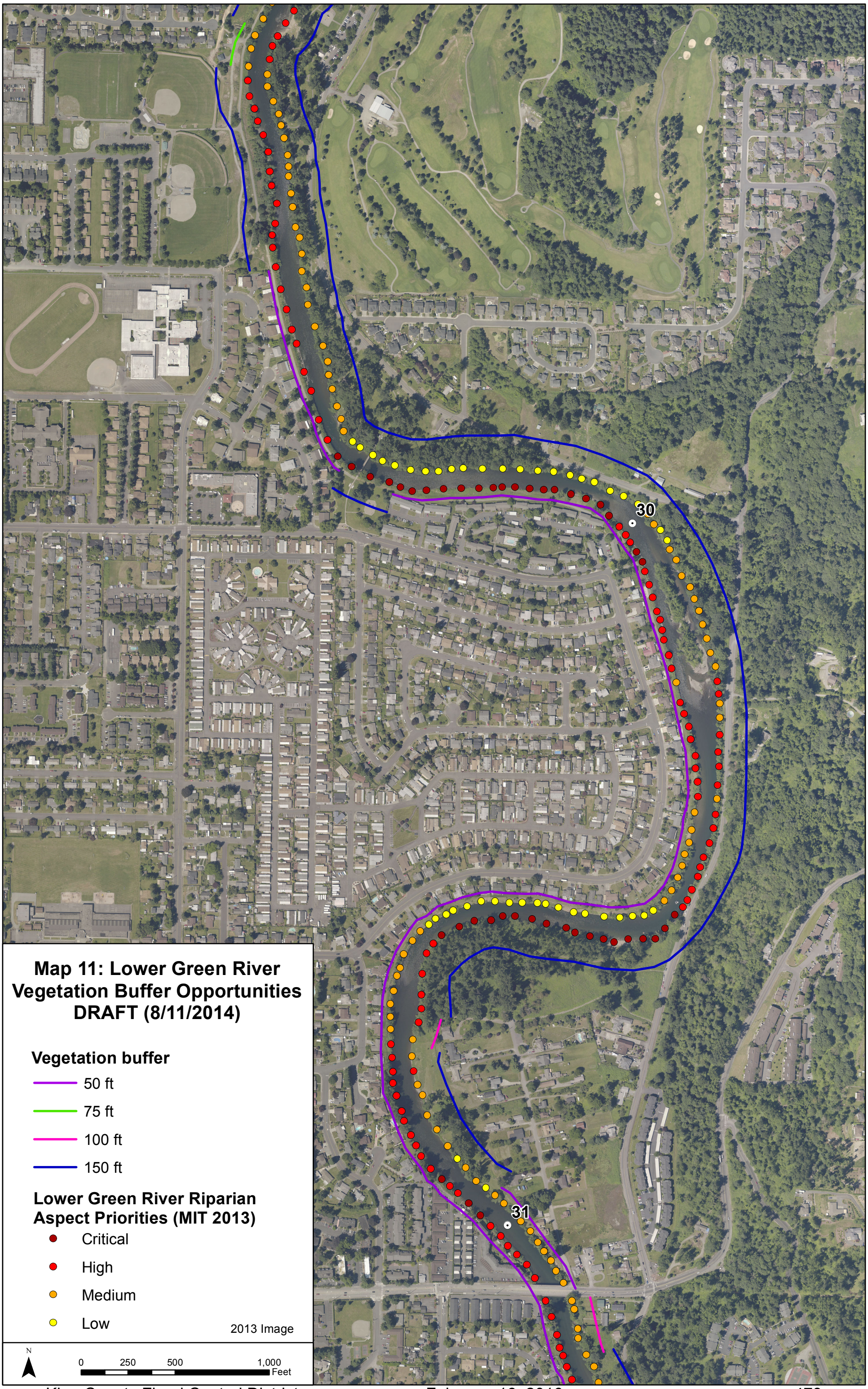

Map 6: Lower Green River Vegetation Buffer Opportunities DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet
20
21
22

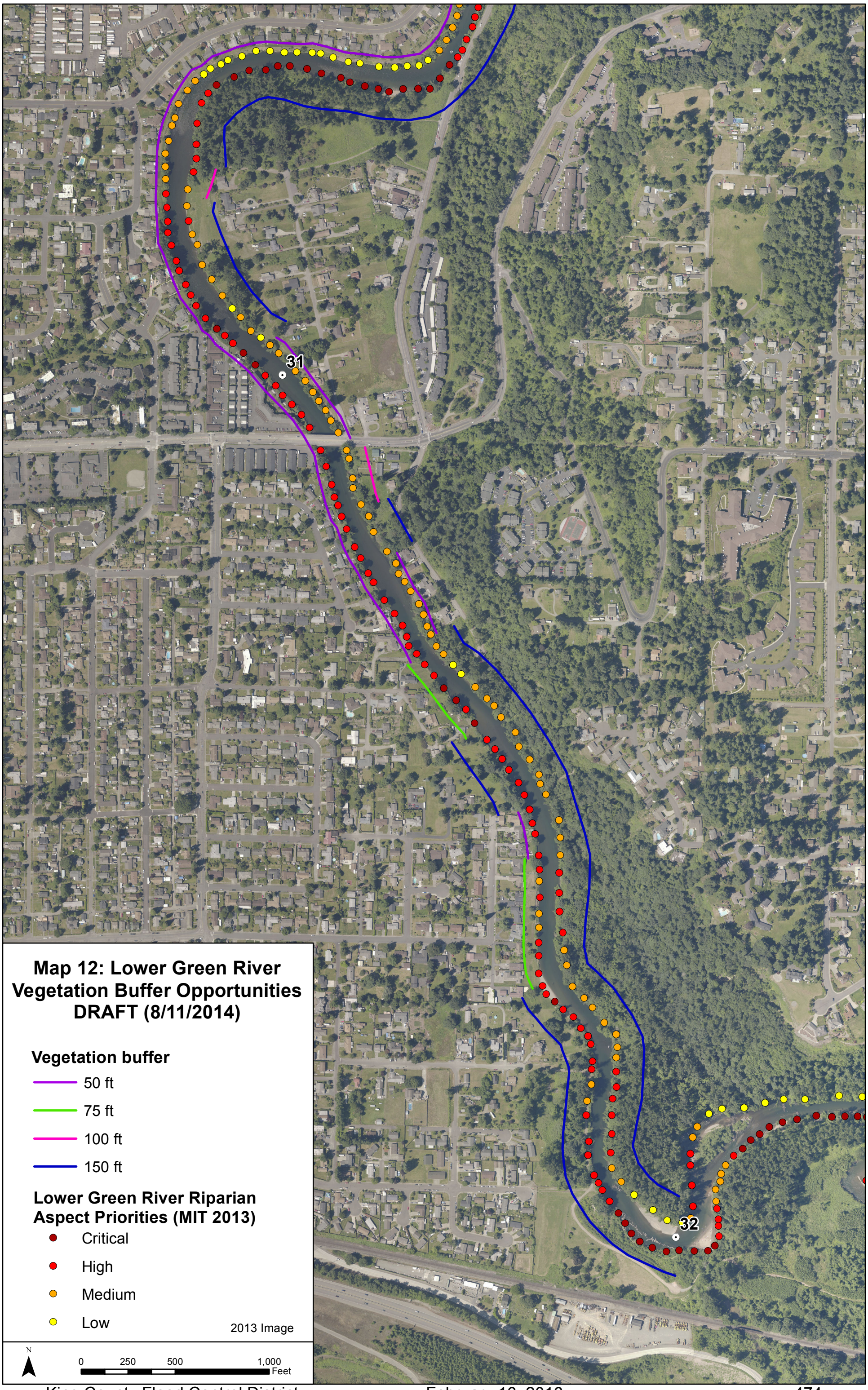

Map 7: Lower Green River Vegetation Buffer Opportunities DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet
22
23
24


Map 8: Lower Green River Vegetation Buffer Opportunities DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet
24
25
26
27


Map 9: Lower Green River
Vegetation Buffer Opportunities
DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian
Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet
27
28


Map 10: Lower Green River Vegetation Buffer Opportunities DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet
28
29


30
31
Map 11: Lower Green River Vegetation Buffer Opportunities DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet


31
32
Map 12: Lower Green River
Vegetation Buffer Opportunities
DRAFT (8/11/2014)
Vegetation buffer
50 ft
75 ft
100 ft
150 ft
Lower Green River Riparian
Aspect Priorities (MIT 2013)
Critical
High
Medium
Low
2013 Image
N
0
250
500
1,000
Feet

# KING COUNTY

1200 King County Courthouse
516 Third Avenue
Seattle, WA 98104

## Signature Report

**February 9, 2016**

**FCD Motion**

**Proposed No.** FCD16-01.1 **Sponsors**

A MOTION establishing the 2016 state legislative agenda for the King County Flood Control Zone District.

WHEREAS, the King County Flood Control Zone District ("District") intends to bring its positions on matters critical to flood protection efforts to the attention of the 2016 Washington state Legislature; and

WHEREAS, the District should work cooperatively with other local governments and other organizations such as King County, the Washington Association of Counties, the Washington Association of County Officials, the Sound Cities Association and the Association of Washington Cities to achieve its 2016 legislative goals; and

WHEREAS, the Legislature has recognized that flood control zone districts have an essential role that is addressing far-reaching and significant threats to public health, public safety and economic activity posed by floods, including ownership of assets; and

WHEREAS, the District funds flood preparedness and flood control projects and King County, as a service provider to the District, delivers these services under interlocal agreement and partnership with the District; and

WHEREAS, the District needs to assure funding to develop flood reduction safety programs and projects in rural, urban, agricultural and industrial areas of King County; and

WHEREAS, sources of revenue for flood reduction safety programs and project development and construction are made possible through numerous sources of external revenue from various state and federal grants and flood reduction and mitigation assistance programs; and

WHEREAS, the board of supervisors of the District desires to adopt a 2016 state legislative agenda; now, therefore

BE IT MOVED BY THE BOARD OF SUPERVISORS OF THE KING COUNTY FLOOD CONTROL ZONE DISTRICT:

SECTION 1. The board of supervisors of the King County Flood Control Zone District adopts the attached 2016 Legislative Agenda, Attachment A to this motion, as the District's highest priorities in the 2016 legislative session of the Washington state Legislature.

KING COUNTY FLOOD CONTROL ZONE DISTRICT
KING COUNTY, WASHINGTON

_____

Reagan Dunn, Chair

ATTEST:

_____

Anne Noris, Clerk of the Board

**Attachments:** A. 2016 Legislative Agenda.docx

**Attachment A**

## 2016 King County Flood Control District State Legislative Agenda

**1. Support for District Capital Projects and Operational Objectives:** ***The District requests the Washington State Legislature to continue funding for these accounts and for other programs that help the district meet its operational goals. The District will continue its work with state agencies and stakeholders to ensure projects meet the flood protection and multi-objective goals of the District.***

The District benefits from programs that support its capital projects and operational goals. For example, the Washington State Flood Control Assistance Account supports capital repair, rehabilitation and improvements throughout King County farming, commercial, and residential areas. Flood Plains by Design provides funding to reduce flood hazards, improve flood water conveyance and facility capacity, restore habitat, and provide safe access to homes and businesses through protection of key transportation routes. Other legislation that may improve the district's ability to meet its operational goals. (ie: Washington Waters Act, demonstration projects)

**2. Support for State Funding for Regional Water Supply Protection:** ***The District supports state funding to stabilize the Lower Snoqualmie River shoreline and protect the Tolt pipeline.***

The District requests assistance and funding for capital projects that have significance to the public safety of the region.

Tolt Pipeline Protection: The Tolt regional water supply pipeline provides 30% of the potable water to the City of Seattle and serves Woodinville, Kirkland, Kenmore, and Shoreline. The rock revetment constructed in the 1960's along the Lower Snoqualmie River is eroding at a rapid rate of five feet per year threatening the stability of the pipeline.

***3.*** **Support for Relocation of Van Doren's Park in Kent as part of the Lower Russell Road Levee Setback Project:** ***The District supports state funding to relocate the City of Kent Van Doren's Park, regional Green River Trail, and public access to the Green River Natural Resources area*****.**

The Lower Russell Road Levee Setback project rebuilds 1.4 miles of the Lower Green River levee system in a location that provides additional space between the river and levee providing flood risk reduction, ecological, and recreational benefits. Multiple stakeholders participated in planning this project including the City of Kent, Muckleshoot Indian Tribe, environmental and business leaders, and federal and state agencies. Stakeholders determined that as part of the project the City of Kent's Van Doren Park will need to be relocated from its current location next to the river. Total project cost for the levee setback project is $42 million.

***4. The District will continue to monitor other relevant legislation impacting its programs and objectives such as the Washington Waters Act and other proposals, including Flood Plains by Design.***