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# 1. INTRODUCTION

To help identify and quantify the effects of land uses on sediment relations and stream bank/channel stability, the Watershed Assessment of River Stability and Sediment Supply (WARSSS) methodologies developed by Rosgen (2009) were used as follows:

1. Reconnaissance-Level Assessment (RLA): This was used to identify current and past land use activities that are contributing to sediment loading and to separate natural geologic erosion rates from human influences. The RLA was used to identify areas of the landscape that contribute the most sediment to receiving waters and existing channel stability problems. As such, it eliminates stable, low-risk slopes; sub-watersheds; and river reaches from further analysis. The RLA provides a broad overview of the landscape while focusing on processes that may affect sediment supply and channel stability.
2. Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC): This builds on the methods and results of the RLA phase to identify, prioritize, and evaluate sensitive landscapes, potentially unstable stream systems, and sediment-generating land use activities.
3. Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS): These are used to evaluate bank characteristics and flow distribution and to map the erosional risk rating within high-potential erosion areas as identified by the RRISSC.
4. The results of the NBS and BEHI survey were used to estimate stream bank erosion rates for each survey reach by using the Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) model.

This report documents the results of the RLA, the RRISSC, BEHI and NBS, and the BANCS model.

# 2. RECONNAISSANCE-LEVEL ASSESSMENT

The RLA is a 15-step process used to identify sediment sources and existing channel stability problems based on a variety of existing and past land practices (Figure 2.1). As such, it eliminates stable, low-risk slopes; sub-watershed; and river reaches from further analysis. The RLA provides a broad overview of the landscape while focusing on processes that may affect sediment supply and channel stability. The remainder of this section is organized by step, as shown in Figure 2.1.

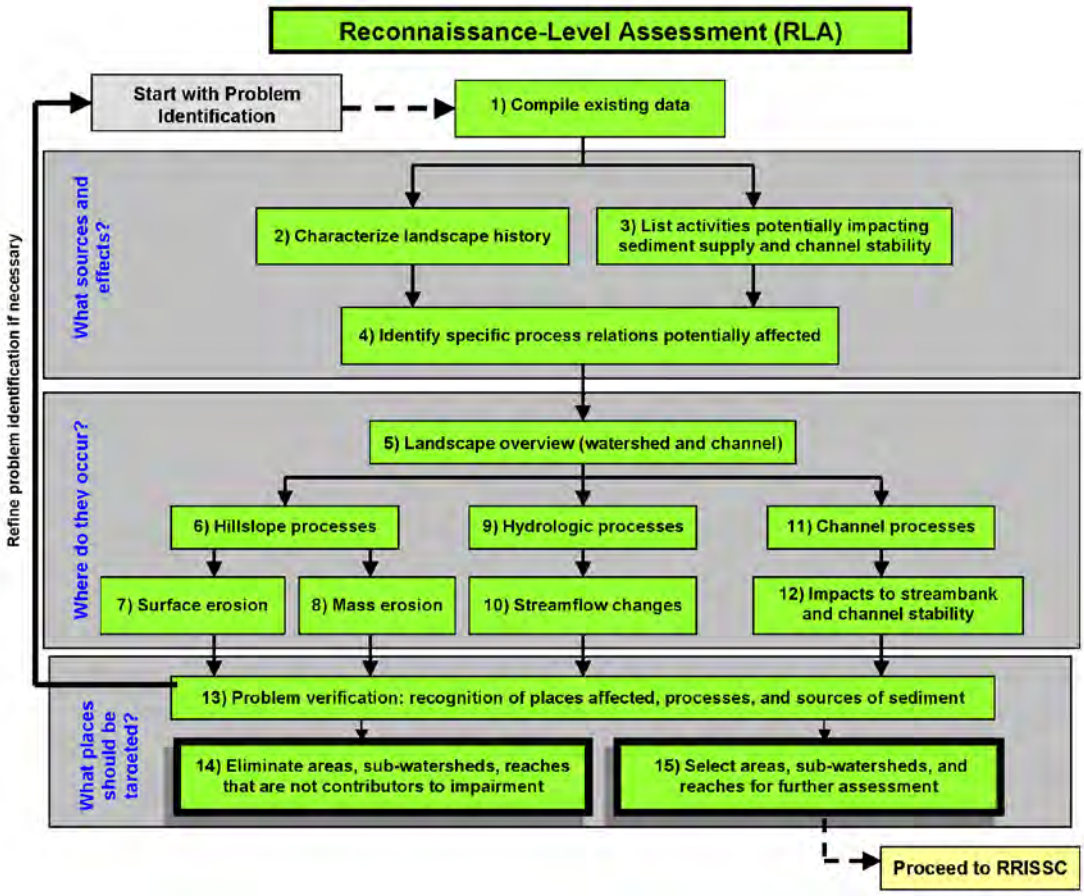
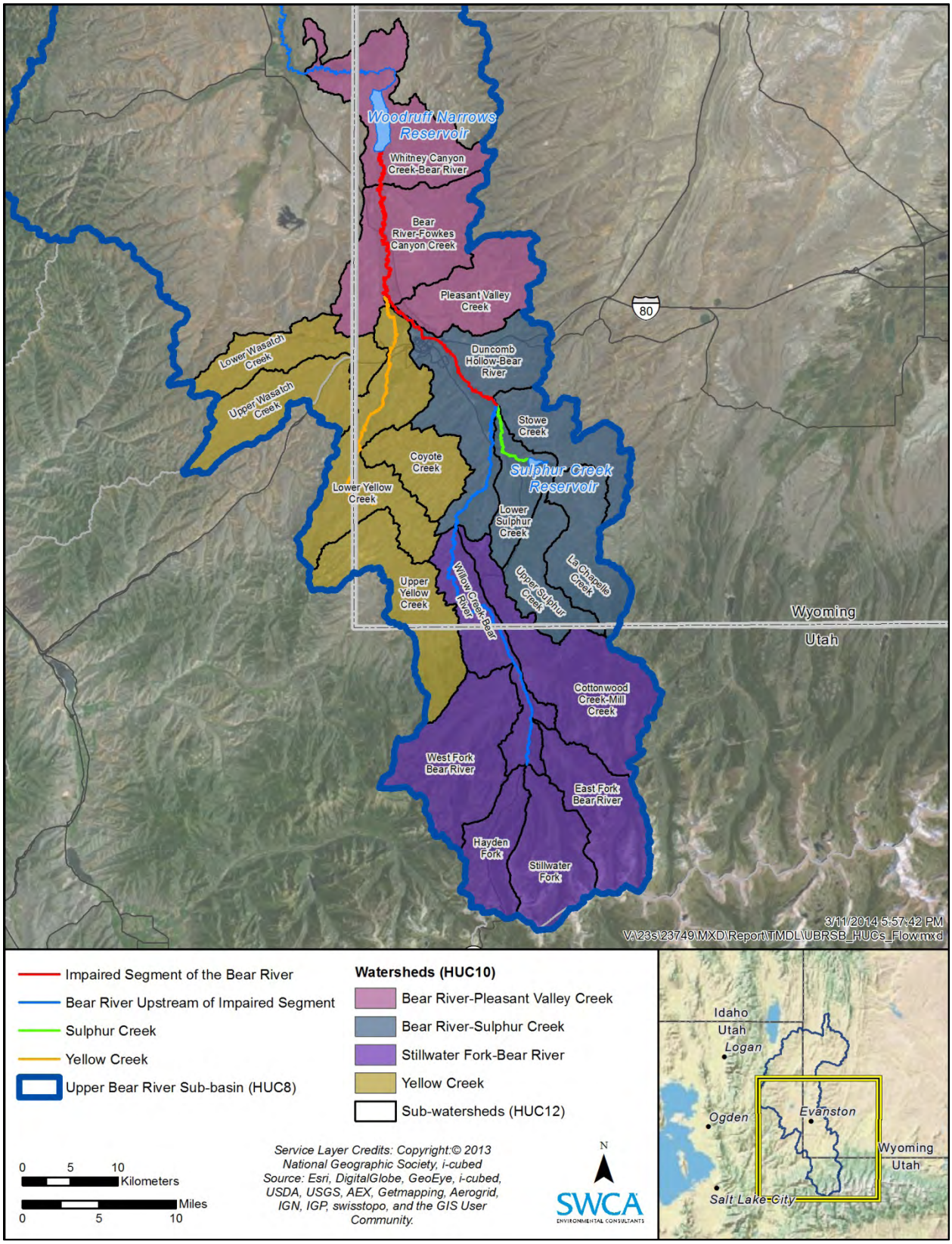



**Figure 2.1**. The RLA step-wise sequence of tasks (taken from U.S. Environmental Protection Agency [EPA] 2008).

## 2.1. Reconnaissance-Level Assessment Study Area

The impaired segment of the Bear River is within the Upper Bear River sub-basin. The RLA study area is defined as the sub-watersheds (Hydrologic Unit Code [HUC]12) within the Upper Bear River sub-basin that flow into the 36.5-mile impaired segment of the Bear River between Woodruff Narrows Reservoir and the confluence with Sulphur Creek. These HUC12 sub-watersheds are in the following four HUC10 watersheds (Map 2-1):

- **Stillwater Fork-Bear River Watershed:** Sub-watersheds are West Fork Bear River, Hayden Fork, Stillwater Fork, East Fork Bear River, Cottonwood Creek-Mill Creek, and Willow Creek-Bear River.
- **Bear River-Sulphur Creek Watershed:** Sub-watersheds are La Chapelle Creek, Upper Sulphur Creek, Lower Sulphur Creek, Stowe Creek, and Duncomb Hollow-Bear River.
- **Yellow Creek Watershed:** Sub-watersheds are Upper Yellow Creek, Lower Yellow Creek, Coyote Creek, Upper Wasatch Creek, and Lower Wasatch Creek.
- **Bear River-Pleasant Valley Creek Watershed:** Sub-watersheds are Pleasant Valley Creek, Bear River-Fowkes Canyon Creek, and Whitney Canyon Creek-Bear River.




**Map 2.1.** Upper Bear River sub-basin sub-watersheds that flow to the impaired segment.

## 2.2. Compile Existing Data (Step 1)

As shown in Figure 2-1, the first step of the RLA is to compile existing data. To conduct the RLA analysis, topographic maps, current and historical aerial imagery, soil data, vegetation layers, and land use data were reviewed for the RLA study area. These data, along with data from various agencies that are compiled and discussed in the Bear River TMDL report, were used to inform the remainder of this RLA.

## 2.3. Characterize Landscape History (Step 2)

Excess sediment within the impaired segment of the Bear River is not only a product of geologic erosion rates, but also a legacy of current and historical land use activities. Within the RLA study area, the primary land uses are grazing, road development, and agriculture, including the conversion of riparian vegetation to agricultural fields and the diversion and damming of water for agricultural use. Surrounding the impaired segment of the Bear River, land use activities are primarily agricultural and urban development. In the upper watersheds, there are recreational development, historic oil, gas activity, gravel mining, and utility development.

### *2.3.1. Water Development*

Water development has played a large role in the support of land uses in the RLA study area. The RLA study area contains water uses for agriculture, livestock, and consumptive uses by municipalities such as Evanston. Irrigation is the largest consumptive water use, using approximately 82% of the available stream flow in Wyoming (Uinta County Conservation District 2005). The City of Evanston also uses surface water from Sulphur Creek and the Bear River. To support these uses, a series of water diversions, canals, in-channel stock dams, “push-up” dams, and reservoirs have been created within most of the sub-watersheds in the RLA study area. The diversion and importation of water within and across sub-watersheds have resulted in direct channel modifications, channel instability including downcutting, meander bend abandonment, formation of new channels, and perennial streams becoming ephemeral.

### *2.3.2. Vegetation Removal and Compaction*

Vegetation in the RLA study area varies based on the elevation and precipitation levels. At the headwaters of the Bear River, in the Stillwater Fork-Bear River watershed, elevations range up to 13,000 feet and receive up to 40 inches of precipitation a year. These areas are primarily evergreen and mixed forests dominated by aspen and conifer forests. At lower elevations in the RLA study area, and close to the impaired segment of the Bear River, the annual precipitation is between 10 and 20 inches. In these areas, the watersheds are dominated by shrub/scrub habitats.

Areas surrounding the main stem of the Bear River, Sulphur Creek below Sulphur Creek Reservoir, and the lower reaches of Yellow Creek have been converted to irrigated pasture and hay meadows. In these areas, riparian forests and wood wetlands have been removed by clear cutting, vegetation treatments, or grazing. The impaired segment of the Bear River has very limited areas of riparian forests or woody wetlands present. Conversion of riparian and upland vegetation to urban development is present around the City of Evanston. The main stem of the Bear River within the Bear River-Fowkes Canyon Creek and Whitney Canyon Creek-Bear River sub-watersheds has considerable emergent herbaceous wetlands present.

### 2.3.3. Soil Compaction and Erosion

The geology in the RLA study area consists of fine-grained formations that create highly erodible soils. The channel of the Bear River is situated in alluvium and colluvium derived from geologic formations that consist of mudstones, siltstones, sandstones, and shales. These formations include the Wasatch, Frontier, Evanston, and the Fowkes Formations. Incised river channels and stream bank erosion of these highly erodible formations and soils have been accelerated by intensive historical grazing practices, road construction, irrigation diversions and return flows, creation of reservoirs and in-channel dams, agricultural crop production, historic phosphate mining, and removal of riparian willow by grazing and chemical spraying (Wyoming Game and Fish Department 2010). As a result, the Bear River has a high natural and human-caused load of fine sediment.

## 2.4. List Activities Potentially Impacting Sediment Supply and Channel Stability (Step 3)

The potential direct and indirect influence of land uses on stream channel stability and sediment supply was assessed based on the current land use in the RLA study area (Table 2.1). This generalized assessment was completed to identify the types and locations of land uses, and the associated potential impacts to sediment supply in the RLA study area. Results of this assessment indicate that grazing, road development, and agriculture (including the conversion of riparian vegetation to agricultural fields and the diversion and damming of water for agricultural use) are the primary land use activities across most of the RLA study area. There is also urban development, recreational development areas, historic oil and gas activity, gravel mining, and utility development. These activities have the potential to impact the following:

- Stream flow
- Riparian vegetation
- Surface disturbance
- Surface/subsurface slope hydrology
- Channel stability
- Clear water discharge
- Stream buffers
- Channel dimension, pattern, and profile
- Sediment deposition and supply
- Large woody debris in the channel
- Stream power
- Channel confinement

## 2.5. Identify Specific Process Relations Potentially Affected (Step 4)

The potential erosional process impacts that could occur based on the current land use activities (see step 3 and Table 2.1) in the RLA study area are summarized in Table 2.1. This assessment was completed to understand the current land use activities and potential erosional process impacts. This assessment indicates that the current land use activities have the potential to cause the following erosional impacts:

- Surface erosion
- Mass erosion
- Gully erosion
- Stream bank erosion
- Channel enlargement
- Aggradation
- Degradation
- Channel succession state
- Sediment delivery efficiency based on stream flow and sediment input changes

**Table 2.1.** Potential Direct and Indirect Influence of Land Use Activities on Stream Channels and Sediment Supply in the RLA Study Area

| **Land Use Activities**<br>**(top row = impact type, bottom row = affected sub-watershed)** | **(1) Stream Flow Changes (magnitude/timing/ duration)** | **(2) Riparian Vegetation Change (composition/density)** | **(3) Surface Disturbance (% bare ground/compaction)** | **(4) Surface/Sub-surface Slope Hydrology** | **(5) Direct Channel Impacts that Destabilize Channel** | **(6) Clear Water Discharge** | **(7) Loss of Stream Buffers, Surface Filters, Ground Cover** | **(8) Altered Dimension, Pattern and Profile** | **(9) Excess Sediment Deposition/Supply (all sources)** | **(10) Large Woody Debris in Channel** | **(11) Stream Power Change (energy distribution)** | **(12) Floodplain Encroachment Channel Confinement (lateral containment)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Urban development | D | D | D | D | D | D | D | D | I | D | D | D |
| | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF |
| Silvicultural | D | D | D | D | D | | D | I | D | D | I | D |
| | CM | CM | CM | CM | CM | | CM | CM | CM | CM | CM | CM |
| Agricultural | D | D | D | D | D | | D | D | D | D | D | D |
| | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV | CM, WB, DB, BF, WCB, US, LC, SC, LY, PV |
| Channelization | D | D | | D | D | | D | D | D | D | D | D |
| | LS, DB, UW, LW, BF, LC, LY | LS, DB, UW, LW, BF, LC, LY | | LS, DB, UW, LW, BF, LC, LY | LS, DB, UW, LW, BF, LC, LY | | LS, DB, UW, LW, BF, LC, LY | LS, DB, UW, LW, BF, LC, LY | LS, DB, UW, LW, BF, LC, LY | LS, DB, UW, LW, BF, LC, LY | LS, DB, UW, LW, BF, LC, LY | LS, DB, UW, LW, BF, LC, LY |
| Flood control (vegetation removal, dredging, levees) | I | D | | D | D | I | D | D | I | D | D | D |
| | DB, BF | DB, BF | | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF | DB, BF |
| Reservoir storage | D | I | | I | D | D | | I | I/D | I | D | |
| | WFB, WB, DB, LY, PV, EB, CM, LC, SC | WFB, WB, DB, LY, PV, EB, CM, LC, SC | | WFB, WB, DB, LY, PV, EB, CM, LC, SC | WFB, WB, DB, LY, PV, EB, CM, LC, SC | WFB, WB, DB, LY, PV, EB, CM, LC, SC | | WFB, WB, DB, LY, PV, EB, CM, LC, SC | WFB, WB, DB, LY, PV, EB, CM, LC, SC | WFB, WB, DB, LY, PV, EB, CM, LC, SC | WFB, WB, DB, LY, PV, EB, CM, LC, SC | |
| Diversions, depletions | D | I | | I | D | D | | | I/D | | | |
| | LY, LC, US, LS, DB, PV, BF, WCB, EB, CM, WB | LY, LC, US, LS, DB, PV, BF, WCB, EB, CM, WB | | LY, LC, US, LS, DB, PV, BF, WCB, EB, CM, WB | LY, LC, US, LS, DB, PV, BF, WCB, EB, CM, WB | LY, LC, US, LS, DB, PV, BF, WCB, EB, CM, WB | | | LY, LC, US, LS, DB, PV, BF, WCB, EB, CM, WB | | | |
| Grazing | I | D | D | D | D | | D | D | D | D | D | |
| | ALL | ALL | ALL | ALL | ALL | | ALL | ALL | ALL | ALL | ALL | |
| Roads | D | | D | D | D | | I | D | D | D | D | D |
| | ALL | | ALL | ALL | ALL | | ALL | ALL | ALL | ALL | ALL | ALL |
| Mining | D | D | D | D | D | | D | D | D | D | D | D |
| | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB | WB, US, LS, SC, LY, BF, SF, EB, CM, DB |
| Energy development (oil and gas and wind) | D | D | D | D | D | | D | D | D | D | D | D |
| | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF | | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF | DB, UY, LY, PV, BF |

*Source*: The structure of this table, including the direct and indirect impact designations by category, is excerpted from WARSSS Worksheet 1b (EPA 2008).

*Notes*: For each listed land use, every sub-watershed location potentially affected across all of the potential impact columns is listed. For each land use activity, the top row lists the type of impact and the bottom row is the affected sub-watersheds.

Impact Types: D = Direct Potential Impact, I = Indirect Potential Impact, Blank = Little to No Potential Impact.

Sub-Watersheds: HF = Hayden Fork, SF = Stillwater Fork, WFB = West Fork Bear River, EB = East Fork Bear River, CM = Cottonwood Creek-Mill Creek, WB = Willow Creek-Bear River, LC = La Chapelle Creek, US = Upper Sulphur Creek, LS = Lower Sulphur Creek, SC = Stowe Creek, DB = Duncomb Hollow-Bear River, UY = Upper Yellow Creek, LY = Lower Yellow Creek, CC = Coyote Creek, UW = Upper Wasatch Creek, LW = Lower Wasatch Creek, PV = Pleasant Valley Creek, BF = Bear River-Fowkes Canyon Creek, WCB = Whitney Canyon Creek-Bear River, ALL = all sub-watersheds in RLA study area.

**Table 2.2.** Relation of Variables Influenced by Identified Land Management Activities and Erosional Impacts for the RLA Study Area

| **Variables Influenced** | **Potential Erosional Process Impacts** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **(top row = impact type, bottom row = affected sub-watershed)** | **Surface Erosion** | **Mass Erosion** | **Gully Erosion** | **Stream Bank Erosion** | **Channel Enlargement** | **Aggradation** | **Degradation** | **Channel Succession State** | **Sediment Delivery Efficiency** |
| (1) Stream flow changes (magnitude/timing/duration) | | I | D | D | D | D | D | D | I |
| | | ALL | ALL | ALL | ALL | ALL | ALL | ALL | ALL |
| (2) Riparian vegetation change (composition/density) | | | D | D | D | D | D | D | I |
| | | | ALL | ALL | ALL | ALL | ALL | ALL | ALL |
| (3) Surface disturbance (% bare ground/compaction) | D | I (Debris Torrents) | D (Rills-Gully) | I | I | I | I | I | D |
| | ALL | ALL | ALL | ALL | ALL | ALL | ALL | ALL | ALL |
| (4) Surface/sub-surface slope hydrology | D | D | D | I | I | I | I | I | D |
| | ALL | ALL | ALL | ALL | ALL | ALL | ALL | ALL | ALL |
| (5) Direct channel impacts that destabilize channel | | | D | D | D | D | D | D | I |
| | | | ALL | ALL | ALL | ALL | ALL | ALL | ALL |
| (6) Clear water discharge | | | D | D | D | I | D | D | |
| | | | DB, BF, WFB, WB, LY, PV, LC, SC, US, LS, WCB, EB, CM | DB, BF, WFB, WB, LY, PV, LC, SC, US, LS, WCB, EB, CM | DB, BF, WFB, WB, LY, PV, LC, SC, US, LS, WCB, EB, CM | DB, BF, WFB, WB, LY, PV, LC, SC, US, LS, WCB, EB, CM | DB, BF, WFB, WB, LY, PV, LC, SC, US, LS, WCB, EB, CM | DB, BF, WFB, WB, LY, PV, LC, SC, US, LS, WCB, EB, CM | |
| (7) Loss of stream buffers, surface filters, ground cover | D | | I | | | | | | D |
| | ALL | | ALL | | | | | | ALL |
| (8) Altered dimension, pattern and profile | | | | D | D | D | D | D | |
| | | | | ALL | ALL | ALL | ALL | ALL | |
| (9) Excess sediment deposition/supply | | | | D | D | D | D | D | |
| | | | | ALL | ALL | ALL | ALL | ALL | |
| (10) Large woody debris in channel | | D | D | D | D | D | D | D | |
| | | ALL | ALL | ALL | ALL | ALL | ALL | ALL | |
| (11) Stream power change (energy redistribution) | | | D | D | D | D | D | D | |
| | | | ALL | ALL | ALL | ALL | ALL | ALL | |
| (12) Floodplain encroachment channel confinement (lateral containment) | | I | I | D | D | D | | I | D |
| | | ALL | ALL | ALL | ALL | ALL | ALL | ALL | ALL |

*Source*: The structure of this table, including the direct and indirect impact designations by category, is excerpted from WARSSS Worksheet 1c (EPA 2008).

Impact Types: D = Direct Potential Impact, I = Indirect Potential Impact, Blank = Little to No Impact.

Sub-Watersheds: HF = Hayden Fork, SF = Stillwater Fork, WFB = West Fork Bear River, EB = East Fork Bear River, CM = Cottonwood Creek-Mill Creek, WB = Willow Creek-Bear River LC = La Chapelle Creek, US = Upper Sulphur Creek LS = Lower Sulphur Creek, SC = Stowe Creek, DB = Duncomb Hollow-Bear River, UY = Upper Yellow Creek, LY = Lower Yellow Creek, CC = Coyote Creek, UW = Upper Wasatch Creek, LW = Lower Wasatch Creek, PV = Pleasant Valley Creek, BF = Bear River-Fowkes Canyon Creek, WCB = Whitney Canyon Creek-Bear River, ALL = all sub-watersheds within RLA study area.

## 2.6. Sediment Supply and Channel Stability Processes (Step 5–12)

A spatial assessment was conducted within each sub-watershed to determine areas and processes that could be contributing to sediment and stability problems in the RLA study area. This assessment was conducted using aerial imagery, topographic maps, inventory information on irrigation diversions and canals, and soil and slope information. A summary of the erosional processes and methods used to identify sediment source areas is described below. The observations made within each sub-watershed of the RLA study area are described within section 2.7.

### *2.6.1. Landscape Overview (Step 5)*

Obvious sediment source areas and/or processes that can adversely affect sediment supply and river stability were identified using aerial imagery. Obvious sediment sources include surface erosion, mass erosion, gully erosion, stream bank erosion, channel enlargement, aggradation, degradation, and channel succession state (see Table 2.2).

### *2.6.2. Hillslope Processes (Step 6)*

Land use activities on hillslopes prone to erosion and/or failures were identified using aerial imagery and soil and slope data.

### *2.6.3. Surface Erosion (Step 7)*

Surface erosion in areas where it is likely to contribute to waterbody sediment supply was identified using aerial imagery, topographic maps, soil maps, and slope data. Areas that met any of the following guidance criteria for advancement to the RRISSC were noted:

- Surface erosion that is evident on steep, dissected slopes
- Surface erosion that is evident on unstable soils at lower slope positions close to drainageways
- Surface erosion from skid trails (temporary roads used by loggers) that are continuous downslope; this erosion directly contributes to the waterbody's sediment supply.
- Surface-disturbing activities that occur on rill-dominated slopes

### *2.6.4. Mass Erosion (Step 8)*

Areas of mass erosion (debris torrents/debris avalanches and/or slump/earthflow) were identified using aerial imagery. Areas that met any of the following guidance criteria for advancement to the RRISSC were noted:

- Evidence of recent (within last 10 years) slump/earthflow and/or debris flow/debris avalanche activity
- Slide activity on steep, concave, continuous slopes
- High percentage of vegetation clearing close to landslide-prone terrain
- Location of slide activity in or adjacent to drainageways

### *2.6.5. Hydrologic Processes (Step 9)*

Changes in the vegetative cover, compaction of soils through the construction of roads, rural development, and urbanization all have the potential to change the magnitude, duration, and timing of

runoff. These changes in runoff can affect the geomorphic character of a stream and its valley type; thus, changing the sediment supply. For purposes of the Bear River TMDL, the stream and valley type classification scheme developed by Rosgen was adopted. Figure 2.2 illustrates Rosgen's stream type classification, and valley type classifications are listed in Figure 2.3. The management interpretations of each stream type's sensitivity to disturbance are provided in Figure 2.4.

Aerial imagery was used to identify areas where land use practices have potentially changed the hydrologic processes, and any direct surface or channel impacts were noted.

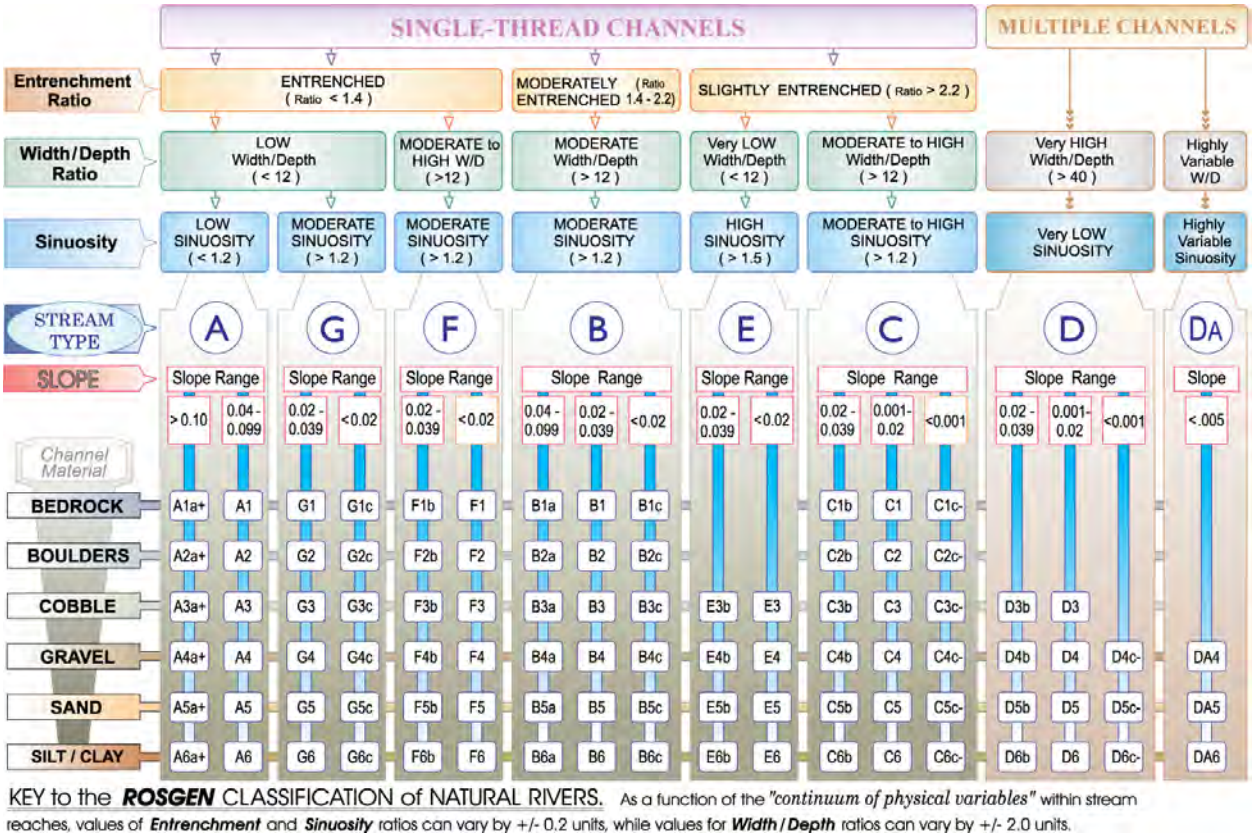



**Figure 2.2**. Stream classification key for natural rivers (Rosgen 1994, 1996). Reprinted with permission from Wildland Hydrology.

| Valley Types | Summary Description of Valley Types | Stream Types |
|---|---|---|
| I | Steep, confined, V-notched canyons, rejuvenated side-slopes | Aa+, A, G |
| II | Moderately steep, gentle-sloping side-slopes often in colluvial valleys | B, G |
| III | Alluvial fans and debris cones | A, B, F, G, D |
| IV | Canyons, gorges and confined alluvial and bedrock-controlled valleys with gentle valley slopes | C, F |
| V | Moderately steep, U-shaped glacial-trough valleys | C, D, F, G |
| VI | Moderately steep, fault-, joint- or bedrock-controlled valleys | Aa+, A, B, C, F, G |
| VII | Steep, fluvial dissected, high-drainage density alluvial slopes | Aa+, A, G |
| VIII | Alluvial valley fills either narrow or wide with moderate to gentle valley slope with well-developed floodplain adjacent to river, and river terraces, glacial terraces or colluvial slopes adjacent to the alluvial valley | C, D, E, F, G |
| IX | Broad, moderate to gentle slopes, associated with glacial outwash or eolian sand dunes | C, D, F |
| X | Very broad and gentle valley slopes associated with glacio- and nonglacio-lacustrine deposits | C, DA, D, E, F, G |
| XI | Deltas | C, D, DA, E |

**Figure 2.3**. Valley type classification key for natural rivers (Rosgen 1994, 1996). Reprinted with permission from Wildland Hydrology.

| Stream Type | Sensitivity to Disturbance[a] | Recovery Potential[b] | Sediment Supply[c] | Streambank Erosion Potential | Vegetation Controlling Influence[d] |
|---|---|---|---|---|---|
| A1 | very low | excellent | very low | very low | negligible |
| A2 | very low | excellent | very low | very low | negligible |
| A3 | very high | very poor | very high | very high | negligible |
| A4 | extreme | very poor | very high | very high | negligible |
| A5 | extreme | very poor | very high | very high | negligible |
| A6 | high | poor | high | high | negligible |
| B1 | very low | excellent | very low | very low | negligible |
| B2 | very low | excellent | very low | very low | negligible |
| B3 | low | excellent | low | low | moderate |
| B4 | moderate | excellent | moderate | low | moderate |
| B5 | moderate | excellent | moderate | moderate | moderate |
| B6 | moderate | excellent | moderate | low | moderate |
| C1 | low | very good | very low | low | moderate |
| C2 | low | very good | low | low | moderate |
| C3 | moderate | good | moderate | moderate | very high |
| C4 | very high | good | high | very high | very high |
| C5 | very high | fair | very high | very high | very high |
| C6 | very high | good | high | high | very high |
| D3 | very high | poor | very high | very high | moderate |
| D4 | very high | poor | very high | very high | moderate |
| D5 | very high | poor | very high | very high | moderate |
| D6 | high | poor | high | high | moderate |
| DA4 | moderate | good | very low | low | very high |
| DA5 | moderate | good | low | low | very high |
| DA6 | moderate | good | very low | very low | very high |
| E3 | high | good | low | moderate | very high |
| E4 | very high | good | moderate | high | very high |
| E5 | very high | good | moderate | high | very high |
| E6 | very high | good | low | moderate | very high |
| F1 | low | fair | low | moderate | low |
| F2 | low | fair | moderate | moderate | low |
| F3 | moderate | poor | very high | very high | moderate |
| F4 | extreme | poor | very high | very high | moderate |
| F5 | very high | poor | very high | very high | moderate |
| F6 | very high | fair | high | very high | moderate |
| G1 | low | good | low | low | low |
| G2 | moderate | fair | moderate | moderate | low |
| G3 | very high | poor | very high | very high | high |
| G4 | extreme | very poor | very high | very high | high |
| G5 | extreme | very poor | very high | very high | high |
| G6 | very high | poor | high | high | high |

[a] Includes increases in streamflow magnitude and timing and/or sediment increases.
[b] Assumes natural recovery once cause of instabiilty is corrected.
[c] Includes supsended and bedload from channel derived sources and/or from stream adjacent slopes.
[d] Vegetation that influences width/depth ratio-stability.

**Figure 2.4**. Management interpretation of various stream types sensitivity to disturbance (Rosgen 1994, 1996). Reprinted with permission from Wildland Hydrology.

## *2.6.6. Stream Flow Changes (Step 10)*

Aerial imagery and diversion and canal information were used to identify areas that have 1) vegetation type conversions, 2) impervious surfaces due to urban development, 3) road development, 4) reservoirs constructed, and 5) diversions, imported water, land drainage, and irrigation return flow. All of these factors have the potential to change the magnitude, duration, and timing of stream flow. Based on Rosgen

(2009) and EPA (2008), areas within a sub-watershed must meet the following criteria to advance to the RRISSC:

1. **Rural (non-urban) watersheds**, where the percentage of bare ground, or hydrologic modification due to change in vegetative type, or clear-cutting timber stands exceeds 30% of second- to third-order watershed area in the presence of A3–A6, C, D, E, F, and G stream types (stream type classification key is provided in Figure 2.2).
2. **Urban watersheds**, where impervious conditions exceed 15% of second- to third-order watershed area in the presence of A3–A6, C, D, E, F, and G stream types, and no hydrologic recovery is identified.
3. **Time-trend of vegetation** (rural or non-urban). If the vegetative conversions occurred within the last 15–20 years for rain-dominant or temperate climates, or 40–70 years for snowmelt-dominated montane and/or sub-alpine climatic regions, indications are likely that there has not been sufficient time for hydrologic recovery. These recovery times are based on revegetating sites and the time necessary to regain pre-treatment evapotranspiration, snow deposition patterns, and other similar processes reflecting consumptive water loss.
4. **Roads**. If roads are located in the lower 1/3 of slope position on moderate to steep slopes (subsurface flow interception). If road densities are over 15% of the watershed area in first- and second-order watersheds. If roads are traversing highly dissected slopes, with multiple stream crossings. If drainageway crossings associated with floodplain fill blockages, and base level changes above and/or below culverts and/or bridges.
5. **Reservoirs**. All reservoirs located on alluvial channel types or those incised in landslide debris, glacial tills, etc. need to be assessed at the RRISSC level or Prediction Level Assessment (PLA). This is due to the complexity of potential impacts, the nature of the stream type, the variation in the operational hydrology of the reservoir, potential ramping flows due to power generation (rapid increases/decreases of flow stage), timing of releases with downstream unregulated tributary flows, and clear water discharge effects.
6. **Diversions, imported water, water depletion and/or return flows**. If the recipient or depleted stream types are alluvial and susceptible to degradation, aggradation, stream bank erosion, enlargement (on stream types A3–A6, C, D, E, F, and G).

### 2.6.7. Channel Processes (Step 11)

Analysis of stream channel processes is critical in this assessment because stream channels transport both water and sediment from their watersheds. The channel morphology (form) and stability and adjacent land use history influence sediment supply and the impairment of designated uses. Based on Rosgen (2009) and EPA (2008), areas within a sub-watershed must meet the following criteria to advance to the RRISSC:

1. There are potential increases in stream flow on the watershed in question associated with A3–A6, C, D, E, F, and/or G stream types.
2. There appear to be stream types that are of the unstable form for a given valley type (i.e., G and F types in valley types II, IX, and X). The observer is reminded to compare reference to existing conditions to determine if the existing stream type is appropriate for the valley type being studied. In other words, if a D stream type was mapped in a valley type IX (glacial outwash valley), it would be indicative of the stable form for that valley type. However, if a D stream type was mapped in valley types II, IV, VI, VIII, or X, it would not represent the typical stable form, and should be flagged to require the RRISSC assessment. Valley type classifications are provided in Figure 2.3.
3. The current stream type departs from the stable form, as indicated in the potential channel evolution or successional stage of channel adjustment relations.
4. Aerial photographs or site visits reveal the following channel-destabilizing processes:
    a. aggradation (excess deposition, wide/shallow)
    b. degradation (incision, floodplain abandonment)
    c. lateral accretion (excess bank erosion)
    d. avulsion (abandonment of previous channels)
    e. enlargement
    f. meandering to braided channels
5. These channel destabilizing processes are observed from either aerial photography or a site visit.
6. Time-trend aerial photography analysis indicates little recovery of apparent channel condition associated with the magnitude, extent, and/or obvious consequence of channel change.
7. Road drainage, stream crossings, or lack of floodplain drains (through-fill crossings) cause adverse channel adjustment.

### 2.6.8. Impacts to Stream Banks and Direct Channel Impacts (Step 12)

Identification of sub-watershed areas with impacts to stream banks or direct channel impacts is addressed in this step. Based on Rosgen (2009) and EPA (2008), areas within a sub-watershed must meet the following criteria to advance to the RRISSC:

1. Stream dimension, pattern, and profile that have been altered due to direct impacts from various sources. The influence of time of disturbance on channel recovery must be considered to determine if a new stable state is developing over time.
2. Evidence exists that riparian vegetation has been reduced, removed, or converted (e.g., woody species to grass).

# 2.7. Problem Verification (Steps 13 and 14)

Observations made during steps 5 through 12 of the RLA were used in step 13 to identify the places affected, the processes, and sources of excess sediment within each sub-watershed of the RLA study area. In step 14, the sub-watersheds, or portions of sub-watersheds that are not contributors of sediment or stability problems, are eliminated. A summary of the results for steps 5 through 14 is provided below for each HUC10 watershed and HUC12 sub-watershed in the RLA study area. The summary below is organized by HUC10 watersheds starting at the headwaters of the Bear River and progressing downstream to Woodruff Narrows Reservoir. A summary of this discussion is provided in Table 2.3 at the end of this section.

## *2.7.1. Stillwater Fork-Bear River Watershed*

### 2.7.1.1. WEST FORK BEAR RIVER

The land use activities in the West Fork Bear River sub-watershed include roads, grazing, and reservoir storage. No surface erosion or mass erosion was identified. The three reservoirs in the sub-watershed are not located in alluvial channel types or incised in landslide debris or glacial tills. No unstable channel processes or impacts to stream bank or channels were identified. This sub-watershed is not included for advancement to the RRISSC because no erosional process impacts were identified.

### 2.7.1.2. HAYDEN FORK

The land use activities in the Hayden Fork sub-watershed include roads, grazing, and recreational campgrounds. Highway 150 and several gravel roads are in the sub-watershed and have stream crossings on tributaries to Hayden Fork. No surface or mass erosion was identified. No unstable channel processes or impacts to stream bank or channels were identified. This sub-watershed is not included for advancement to the RRISSC because no erosional process impacts were identified.

### 2.7.1.3. STILLWATER FORK

The land use activities in the Stillwater Fork sub-watershed include mining, roads, grazing, and recreational campgrounds. These activities are restricted to the lower half (northern portion) of the sub-watershed. In this portion of the sub-watershed, the valley type is a V, or moderately steep valley slopes with “U” shaped glacial trough valleys. In this portion of the sub-watershed, the main stem of Stillwater Fork is a C, F, and B stream.

Aerial imagery indicates that areas of the Stillwater Fork sub-watershed upstream of the Stillwater Fork Road crossing of Stillwater Fork River do not exhibit any land use activities or areas of surface or mass erosion, unstable channel processes, or impacts to stream bank or channels and therefore were eliminated from advancement to the RRISSC. One mine and a gravel access road are located along Main Fork and the road crosses Stillwater Fork.

No surface erosion, mass erosion, or unstable channel processes or impacts to stream bank or channels were identified within the Main Fork drainage in relation to this mine and access road; therefore, the Main Fork drainage was eliminated from advancement to the RRISSC.

Roads occur within the lower half (northern portion) of the sub-watershed, and there are two bridge stream crossings on Stillwater Fork. Recreational campgrounds and roads are present along the east side of Stillwater Fork. The main stem of Stillwater Fork, downstream of the Stillwater Fork Road Crossing, does exhibit unstable channel processes, including lateral accretion (excess bank erosion) and meandering

to braided channels (Figure 2.5 and Figure 2.6). These channel processes were identified on aerial imagery dating back to 1993.This section of the Stillwater Fork is recommended for advancement to the RRISSC due to the observations of unstable channel processes. Topography lines indicating flow direction were used to define the RLA study area for advancement to the RRISSC.

**Figure 2.5**. Lateral accretion and enlargement on Stillwater Fork (40°50'33"N, 110°49'17"W).

**Figure 2.6**. Lateral accretion, enlargement, and avulsion on Stillwater Fork (40°50'45"N, 110°49'29"W).

## 2.7.1.4. EAST FORK BEAR RIVER

The land use activities in the East Fork Bear River sub-watershed include roads, grazing, two irrigation diversions, and recreational campgrounds, including a Boy Scout camp with three off channel ponds to the east of the Bear River. These activities are restricted to the lower half (northern portion) of the sub-watershed.

A fire occurred in the sub-watershed in 2002, resulting in a vegetative change within 8,936 acres of the sub-watershed. Between 2006 and 2011, a few A and B stream type tributaries experienced channel processes, including later accretion and evolution to G and D stream types. Alluvial fans formed at the mouth of these tributaries with D stream types or braided channels (Figure 2.7). A review of aerial imagery indicates that the formation of the D channel and alluvial fans may have prevented sediment from reaching the main stem of Stillwater Fork. A review of aerial imagery indicates that no change has occurred in these tributaries between 2011 and 2013. These tributary streams are not likely to be a current sediment source to the Stillwater Fork and were eliminated from advancement to the RRISSC.

Channel processes, including lateral accretion and avulsion, are evident on the main stem of the East Fork Bear River (Figure 2.8). Aerial imagery indicates that these channel process have worsened between 2009 and 2011, indicating channel recovery has not occurred. These channel processes may have been the result of the vegetative changes within the sub-watershed as a result of the 2002 fire. The irrigation diversions occur on B stream types that are not susceptible to unstable channel processes.

Areas selected for advancement to the RRISSC include the East Fork Bear River downstream of the Boy Scout camp within a valley type II and stream types B, C, and D and the sub-watershed to the east of the

East Fork Bear River. These areas represent potential sediment source areas to the Bear River. Topography lines indicating flow direction were used to define the RLA study area for advancement to the RRISSC.

**Figure 2.7**. Channel aggradation and avulsion along tributary streams between 2006 and 2011 forming an alluvial fan near the confluence with the East Fork Bear River (40°52'29"N, 110°46'43"W). Top photograph was taken September 24, 2006. Bottom photograph was taken October 2, 2011.

**Figure 2.8**. Latter accretion and avulsion on the East Fork Bear River (40°52'53"N, 110°47'32"W).

## 2.7.1.5. COTTONWOOD CREEK-MILL CREEK

Land use activities in the Cottonwood Creek-Mill Creek sub-watershed include silviculture, agriculture, irrigation diversions, grazing, roads, and mining. Silviculture has occurred in the headwaters of Mill Creek, Pilot Creek, and Carter Creek. The extent of the silviculture is unknown. These areas have an extensive network of two-track roads that are in steep terrain and close to A stream types, which are steep gradient streams that are more susceptible to erosional and channel changes (Figure 2.9). The upper sub-watershed also contains a high density of four-wheel-drive trails in first-order streams that are close to streams and erosive soils. Cottonwood Creek-Mill Creek meets criterion 6 under step 10 (stream flow changes) for advancement to the RRISSC due the road location within the lower 1/3 of slope position on moderate to steep slopes (sub-surface flow interception). An example of the surface erosion and channel impacts occurring along Cow Hollow, within the subwatershed in Utah, is shown in Figure 2.10. Based on a review of aerial imagery, this erosion has increased since 2009.

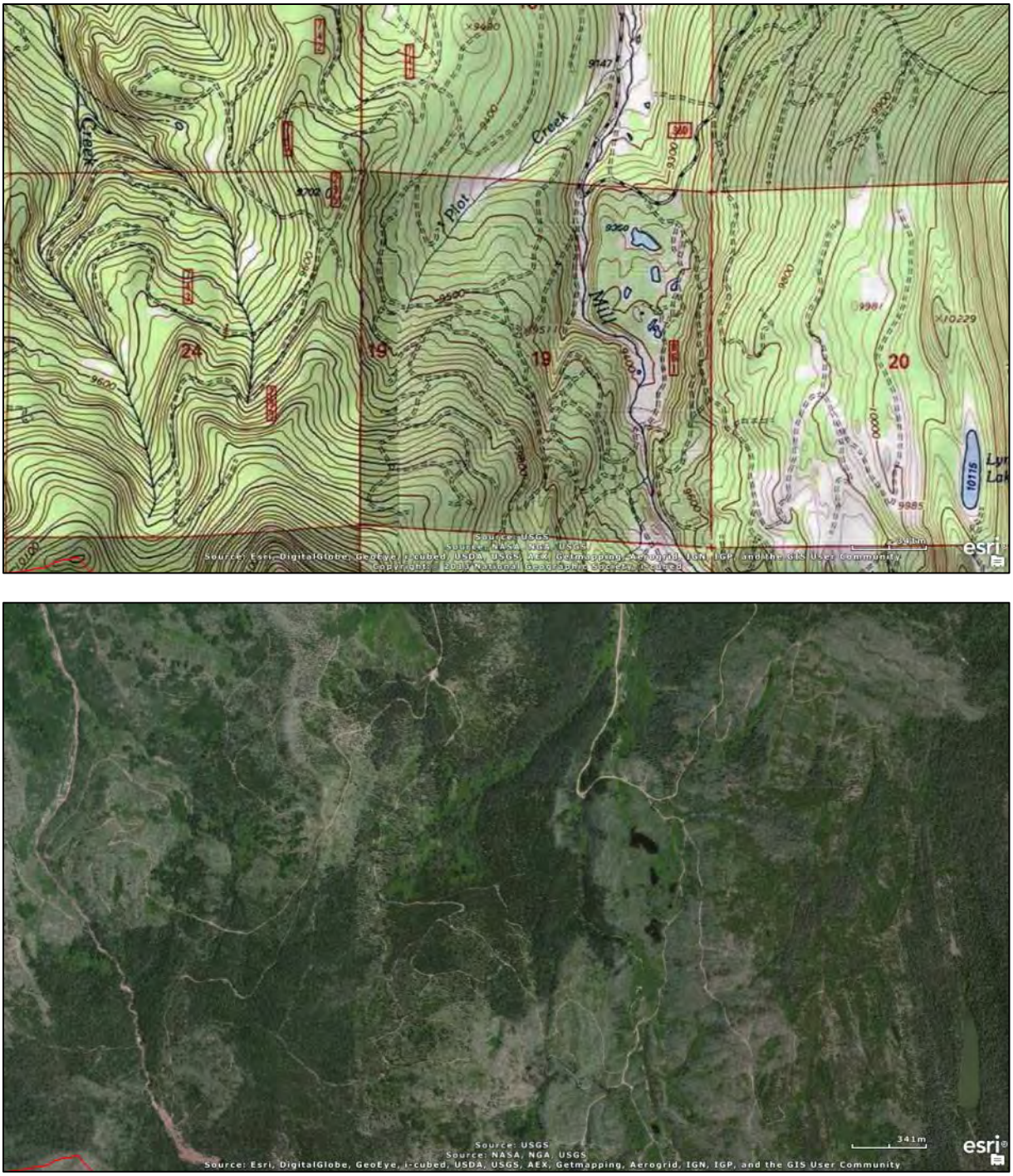



**Figure 2.9.** Topographic map (top) and aerial imagery (bottom) showing the network of roads (dashed black lines) in silviculture area near Mill Creek, Pilot Creek, and Carter Creek (40°53'51"N, 110°45'50"W).

**Figure 2.10**. Aerial imagery showing the network of roads, surface erosion, and channel erosion in Cow Hollow, Utah (40°58'10"N, 110°47'32"W).

A fire also occurred in this sub-watershed in 2002, covering portions of Mill Creek, Carter Creek, Christmas Tree Creek, and North Fork Creek. A review of aerial imagery reveals that channel-destabilizing processes have occurred along a large portion of Carter Creek between 2009 and 2011. These processes include lateral accretion and the formation of a large head-cut in the headwaters (Figure 2.11).

Irrigation diversions in support of agriculture occur in the lower watershed off the main stem of Mill Creek. Both water depletions and return flows from the Mill Creek and the Bear River occur in this sub-watershed. Chanel impacts from water depletions and return flow are occurring. These channel processes include lateral accretion (excess bank erosion), avulsion, and enlargement (Figure 2.12). Extensive vegetation conversion to agriculture has also occurred along the main stem of Mill Creek. Surface erosion, mass erosion, gully erosion, stream bank erosion, and channel impacts are occurring in areas across the sub-watershed. This sub-watershed was selected for advancement to the RRISSC.

**Figure 2.11.** Aerial imagery showing lateral accretion and head-cutting, which occurred between 2009 and 2011 on Carter Creek (40°53'10"N, 110°45'38"W).

**Figure 2.12**. Aerial imagery showing lateral accretion, avulsion, and enlargement on Mill Creek (40°57'39"N, 110°49'07"W).

## 2.7.1.6. WILLOW CREEK-BEAR RIVER

Land use activities in the Willow Creek-Bear River sub-watershed include rural housing development, agriculture, channelization, reservoir storage, diversions for agriculture within and outside of the sub-watershed, grazing, roads, and mining. The largest impacts to the Bear River are occurring from water withdrawals from irrigation diversions, conversion of native vegetation to agricultural fields, and direct channel impacts including channelization, bank armoring, and cross-channel diversion dams. These impacts are primarily concentrated downstream of the inflow from the West Fork Bear River. Stream bank erosion, channel enlargement, avulsion, and braiding of the channel are evident in aerial imagery (Figures 2-13 through 2-15). Mining and surface erosion are also occurring directly adjacent to the Bear River (Figure 2.13). This sub-watershed was selected for advancement to the RRISSC.

**Figure 2.13**. Aerial imagery showing gravel mine along the main stem of the Bear River (40°52'36.69"N, 110°50'10.85"W).

**Figure 2.14**. Aerial imagery showing channelization/armoring of a meander bend, and two irrigation diversion dams and canals. The canal on the east side of the Bear River is Lewis Canal, which diverts water into the Cottonwood Creek-Mill Creek sub-watershed (41°03'16"N, 110°55'51"W).

**Figure 2.15**. Aerial imagery showing channel avulsion, lateral accretion, and vegetation changes downstream of the Lewis Canal (41°05'01"N, 110°55'35"W).

## 2.7.2. Bear River-Sulphur Creek Watershed

### 2.7.2.1. UPPER SULPHUR CREEK

Land use activities in the Upper Sulphur Creek sub-watershed include agriculture, diversions, grazing, roads, and mining. Water is imported into this sub-watershed from the Bear River in the Willow Creek-Bear River sub-watershed, Mill Creek in the Cottonwood Creek-Mill Creek sub-watershed, and Austin Reservoir in LaChapelle Creek sub-watershed. Sulphur Creek also has irrigation diversions on the main channel. Aerial imagery indicates that Sulphur Creek has enlarged and straightened its channel, abandoning some of its meanders. Water depletions and limited irrigation return flow to Sulphur Creek may be reducing the amount of channel destabilizing that is occurring. Some areas of Sulphur Creek have been armored, and much of its riparian vegetation has been removed or is no longer receiving sufficient water to survive. Sediment supplies from the Upper Sulphur Creek sub-watershed settles out within Sulphur Creek Reservoir before reaching the Lower Sulphur Creek sub-watershed. As a result, the Upper Sulphur Creek sub-watershed is not recommended for advancement to RRISSC.

### 2.7.2.2. LACHAPELLE CREEK

Land use activities in the LaChapelle Creek sub-watershed include agriculture, channelization, reservoir storage, diversions, grazing, and mining. Water depletions from Willow Creek and LaChapelle Creek are diverted to Austin Reservoir and another unnamed reservoir and are also used for irrigating crops. Water is also diverted into the Upper Sulphur Creek sub-watershed. LaChapelle Creek has channel destabilization and has been channelized for agricultural field expansion. LaChapelle Creek appears to have low flows due to diversions, which may be reducing the amount of channel destabilization occurring, or the channel has recovered to a stable channel form. Sediment supplies from the LaChapelle Creek sub-watershed settle out within Sulphur Creek Reservoir before reaching the Lower Sulphur Creek sub-watershed. As a result, the LaChapelle Creek sub-watershed is not recommended for advancement to RRISSC.

### 2.7.2.3. STOWE CREEK

Land use activities in the Stowe Creek sub-watershed include limited agriculture, reservoir and pond storage for cattle, grazing, roads and railroad, and mining. The soils in the Stowe Creek sub-watershed are erosive, and there is primarily shrub/scrub vegetative cover. Some surface erosion and channel erosion are identified in this sub-watershed. A review of aerial imagery from 1994 to 2013 indicates that stream channels and surface erosion are stable and not currently contributing sediment to the Lower Sulphur Creek sub-watershed. The Stowe Creek sub-watershed is not recommended for advancement to the RRISSC because erosional processes appear to have stabilized within the last 15 years.

### 2.7.2.4. LOWER SULPHUR CREEK

Land use activities in the Lower Sulphur Creek sub-watershed include agricultural development, channelization, reservoir storage, irrigation diversions, importation of water, and mining. The main stem of Sulphur Creek downstream of Sulphur Creek Reservoir was identified as a sediment source area to the impaired segment of the Bear River. The main stem of Sulphur Creek has stream flow changes associated with water releases from Sulphur Creek Reservoir, resulting in channel instability (Figure 2.16). It has stream stability impacts from road crossings and fill (Figure 2.17), the channel shows evidence of channel-destabilization processes (Figure 2.18), the channel has been altered through channelization (Figure 2.17), and riparian vegetation has been changed from woody plants to a grass/forb community (Figure 2.18). The main stem of Sulphur Creek downstream of Sulphur Creek Reservoir is recommended for advancement to the RRISSC.

The Lower Sulphur Creek sub-watershed, located south and south west of Sulphur Creek Reservoir, has agricultural lands that are irrigated primarily by importation of water from the Bear River, but also from diversions and reservoirs from Bozo Hollow Creek. Imported water primarily flows into on-channel ponds or directly onto fields. No channel instability in tributary streams to Sulphur Creek was identified on aerial imagery. Water from these diversions is used for agricultural development and gravel mining operations. Return flows appear to be limited to the main stem of Sulphur Creek based on the lack of return flow canals to Sulphur Creek and the size and vegetation cover in the channels of natural tributaries. Some return flows are also captured within Sulphur Creek Reservoir.

The Lower Sulphur Creek sub-watershed located north and northeast of Sulphur Creek has agricultural development near the main stem of Sulphur Creek and road development. The upland areas have naturally erosive soils and some natural gullies; however, there is limited development in these areas. Sediment contribution to the main stem of Sulphur Creek appears to be limited based on a review of aerial imagery. Agricultural fields occur between these erosive areas and the main stem of Sulphur Creek. The leveling of the agricultural fields and the vegetation cover and density may act as a filter for sediment reaching the main stem of Sulphur Creek.

Sulphur Creek upstream of Sulphur Creek Reservoir and the uplands south, west, and northeast of the main stem of Sulphur Creek are not recommended for advancement to the RRISSC. The remaining portion of the Lower Sulphur Creek sub-watershed is retained for advancement to the RRISSC.

**Figure 2.16**. Aerial imagery showing channel instability (head-cuts and degradation) of Sulphur Creek downstream of Sulphur Creek Reservoir (41°09'14"N, 110°50'20"W).

**Figure 2.17**. Aerial imagery showing channelization and channel instability associated with channel confinement for road crossings on Sulphur Creek (41°09'22"N, 110°50'55"W).

**Figure 2.18.** Aerial imagery showing channel instability, including degradation associated with channel confinement for roads and the conversion of riparian vegetation to grasses and forbs on Sulphur Creek (41°11'20"N, 110°51'59"W).

## 2.7.2.5. DUNCOMB HOLLOW-BEAR RIVER

Land use activities in the Duncomb Hollow-Bear River sub-watershed include urban development, agriculture, channelization, flood control, reservoir storage, diversions, grazing, roads, mining, energy development, and utility corridor development. The Bear River upstream of the confluence with Sulphur Creek has been influenced primarily by agriculture and irrigation and diversions for the City of Evanston.

The Bear River downstream of the confluence with Sulphur Creek is influenced by agricultural development, irrigation diversions, flow alterations from Sulphur Creek Reservoir, and urban development. Surface erosion was identified on unstable soils close to drainageways along the Bear River and Duncomb Hollow. Diversions in this sub-watershed are in alluvial soils that are susceptible to erosive channel processes. The density of roads is high in this sub-watershed, with floodplain fill blockages and direct channel impacts such as channelization. A review of aerial imagery indicates that multiple channel destabilization process are occurring, with very limited recovery identified. As an example, the Bear River has experienced aggradation, lateral accretion, and avulsion downstream of the City of Evanston between 2009 and 2011 (Figure 2.19).

On the east side of the Bear River, Duncomb Hollow and Blake Hollow flow into the Bear River. Duncomb Hollow has been directly impacted by extensive channelization and floodplain encroachment by Interstate 80 (I-80). Blake Hollow has some surface erosion present and has multiple pipeline corridors occurring along the main stem.

In the upland areas on the west side of the Bear River, there are two main irrigation ditches: the Old City Ditch and the City Aqueduct Ditch; both divert water from the Bear River to the City of Evanston and into other sub-watersheds. These irrigation ditches intercept water and sediment input from the southeast side of the Bear River, including water from Knight Hollow, Glasscock Hollow, Bernard Hollow, and Sandy Ridge. No erosional processes were identified in the upland areas west of these two ditches. The upland areas that are west of the Old City Ditch and City Aqueduct Ditch were excluded from advancement to the RRISSC. Excluding the areas that drain to these ditches, the Duncomb Hollow-Bear River sub-watershed was recommended for advancement to the RRISSC.

**Figure 2.19**. Aerial imagery of channel processes, including avulsion, aggradation, and enlargement that occurred on the Bear River downstream of Evanston between March 27, 2010 (top photograph) and October 2, 2011 (bottom photograph) (41°17'57"N, 110°59'56"W).

## 2.7.3. Yellow Creek Watershed

### 2.7.3.1. UPPER YELLOW CREEK

Land use activities in the Upper Yellow Creek sub-watershed include oil and gas development, grazing, and in channel stock pond development. Infrastructure related to oil and gas development includes a large processing station, oil and gas well pads, pipelines, and access roads. A review of aerial imagery indicates that no surface erosion, mass erosion, stream flow change, channel processes impacts, or direct channel impacts are occurring within this sub-watershed. This sub-watershed is not recommended for advancement to the RRISSC.

### 2.7.3.2. LOWER YELLOW CREEK

Land use activities in the Lower Yellow Creek sub-watershed include agriculture, stream channelization, reservoir storage, irrigation diversions, grazing, roads, gravel mining, and energy development. Surface erosion is evident on steep slopes and unstable soils along the outfall of Barker Reservoir into Yellow Creek (Figure 2.20). Stream flow changes have occurred on the main steam of Yellow from the diversion of water and the depletion of stream flows. Yellow Creek is in alluvial soils and is susceptible to stream bank erosion from changes in stream flow. Streambank erosion is evident on Yellow Creek as a result of stream flow changes due to water depletions from irrigation diversion (Figure 2.21 and 2.22), alterations in flows from operation of Barker Reservoir (Figure 2.20), and floodplain and fill impacts associated with road crossings.

Channel destabilization processes have occurred on Yellow Creek as a result of the development of irrigation diversion structures, water depletions from irrigation diversion, agricultural development, channelization for interstate and road development, and road crossings. These channel processes include degradation, lateral accretion, and avulsion. Direct channel impacts have also occurred on Yellow Creek as a result of channelization and the construction of irrigation diversion dams. A review of aerial imagery indicates that multiple channel destabilization processes are occurring, with very limited recovery identified.

A review of aerial imagery indicates that impacts from erosional processes are primarily occurring on the main stem of Yellow Creek below Barker Reservoir. Potential sediment upstream of Barker Reservoir in Yellow Creek, Spring Creek, and Chicken Creek settles out in Barker Reservoir and does not reach the Bear River. Additionally, sediment in the Sage Creek drainage also settles out in an unnamed reservoir on the main stem of Sage Creek. As a result, the watershed areas upstream of Barker Reservoir and upstream of the unnamed reservoir on Sage Creek are not recommended for advancement to the RRISSC. The drainage area contributing to Lower Yellow Creek downstream of Barker Reservoir was recommended for advancement to the RRISSC.

**Figure 2.20**. Erosion on steep slopes with unstable slopes from the development of the overflow channel for Barker Reservoir (41°07'34"N, 111°03'25"W). Sediment is flowing into Yellow Creek.

**Figure 2.21**. Stream bank erosion downstream of an irrigation diversion (indicated by the red arrow) that is depleting water from Yellow Creek (41°08'52"N, 111°03'03"W).

**Figure 2.22.** Main stem of Yellow Creek with channelization along the interstate and water depletions from two irrigation diversion (indicated by the red arrows). The main stem of Yellow Creek has significant flow reductions downstream of these two diversions (41°15'56"N, 111°00'01"W).

### 2.7.3.3. COYOTE CREEK

Land use activities in the Coyote Creek sub-watershed include roads, grazing, and oil and gas development. Development in this sub-watershed is very limited. A review of aerial imagery indicates that no surface erosion, mass erosion, stream flow change, channel processes impacts, or direct channel impacts are occurring within this sub-watershed. This sub-watershed is not recommended for advancement to the RRISSC.

### 2.7.3.4. UPPER WASATCH CREEK

Land use activities in the Upper Wasatch Creek sub-watershed include channelization, grazing, and roads. A review of aerial imagery indicates that approximately 1 mile of the main stem of Wasatch Creek has been channelized or confined due to the railroad and interstate (Figure 2.23). This channelization and confinement also continues downstream into the Lower Wasatch Creek sub-watershed. Potential channel recovery on the main stem of Wasatch Creek will need to be assessed during the RRISSC. A review of aerial imagery indicates that no surface erosion, mass erosion, stream flow change, channel processes impacts, or direct channel impacts are occurring outside of the main stem of Wasatch Creek.

**Figure 2.23**. Channelization (marked by red line) of Wasatch Creek by the railroad. Note the abandonment of the original meandering stream channel (41°13'59"N, 111°04'59"W).

## 2.7.3.5. LOWER WASATCH CREEK

Land use activities in the Lower Wasatch Creek sub-watershed include channelization, grazing, and roads. A review of aerial imagery indicates that approximately 1.4 mile of the main stem of Wasatch Creek has been channelized or confined due to the railroad and interstate (Figure 2.24). Potential channel recovery on the main stem of Wasatch Creek will need to be assessed during the RRISSC. A review of aerial imagery indicates that no surface erosion, mass erosion, stream flow change, channel processes impacts, or direct channel impacts are occurring outside of the main stem of Wasatch Creek.

**Figure 2.24.** Channelization (start marked by red arrow) of Wasatch Creek by the interstate. Note the abandonment of the original meandering stream channel on north side of the interstate (41°14'55"N, 111°02'04"W).

## *2.7.4. Bear River-Pleasant Valley Creek Watershed*

### 2.7.4.1. PLEASANT VALLEY CREEK

Land use activities in the Pleasant Valley Creek sub-watershed include agriculture, reservoir storage, diversions, grazing roads, and energy development, including oil, gas, and wind. Pleasant Valley Creek is the main tributary to the Bear River within this sub-watershed. Pleasant Valley Creek has two main channel reservoirs, Painter Reservoir and Crompton Reservoir. Painter and Crompton Reservoirs both maintain active pools and act as sediment basins from upland areas. A review of aerial imagery indicates that most of the flow leaving Crompton Reservoir travels through an irrigation ditch and is used to irrigate multiple agricultural fields. John Sims Ditch also originates from the Bear River and travels north through the sub-watershed collecting irrigation return flows and any flows that are within Pleasant Valley Creek. Approximately 530 feet of the Bear River flows into this sub-watershed and has experienced recent erosional channel processes, including avulsion, aggradation, and enlargement. If erosion continues to cut off the meander bend, the Bear River will no longer flow through this sub-watershed.

As a result of the sediment captured by reservoirs, and the presence of irrigation canals intercepting return flows, this sub-watershed is not recommended for advancement to the RRISSC.

### 2.7.4.2. BEAR RIVER-FOWKES CANYON CREEK

Land use activities in the Bear River-Fowkes Canyon Creek sub-watershed include agriculture, channelization, flood control, diversions, grazing, roads, and energy development. The Bear River has been impacted by agricultural development, irrigation diversions, flow alterations from Sulphur Creek Reservoir, channel confinement, and channelization. Diversions within this sub-watershed are in alluvial soils that are susceptible to erosive channel processes. The density of roads is high in this sub-watershed,

with floodplain fill blockages and direct channel impacts such as channelization. A review of aerial imagery indicates that multiple channel destabilization process are occurring, with very limited recovery being apparent. As an example, the Bear River has experienced degradation, lateral accretion, and oxbow cutoff between 2004 and 2009 (Figure 2.25). The main stem of the Bear River, Red Willow Creek, and Dry Canyon meet the criteria for advancement to the RRISSC.

An review of aerial imagery indicates that upland areas west of the Bear River have surface erosion, stream flow changes from creation of roads and housing developments, unstable stream forms, degradation, channel enlargement, and direct channel impacts from the creation of roads and installation of in-channel dams. However, flow and sediment from these upland areas are isolated from the Bear River by irrigation canals, including the Chapman Canal, which capture flows from upland areas and divert them into Woodruff Narrows Reservoir. Therefore, the upland areas west of the Bear River are not recommended for advancement to the RRISSC.

A review of aerial imagery indicates that upland areas east of tunnel canal, including Fowkes Canyon Creek, have experienced surface erosion, stream flow changes from roads, and channel process impacts from road crossings on Fowkes Canyon Creek. However, flow and sediment from these upland areas are isolated from the Bear River by Tunnel Ditch, which captures flows from upland areas and diverts them into Woodruff Narrows Reservoir. Therefore, the upland areas east of tunnel are not recommended for advancement to the RRISSC.

**Figure 2.25**. Aerial imagery of channel processes, including lateral accretion and oxbow cutoff that occurred on the Bear River between September 14, 2004 (top photograph) and August 29, 2009 (bottom photograph) (41°20'33.62"N, 111° 0'30.66"W).

#### 2.7.4.3. WHITNEY CANYON CREEK-BEAR RIVER

Land use activities in the Whitney Canyon Creek-Bear River sub-watershed include agriculture, channelization, diversions and irrigation return flow, grazing, and roads. The Bear River in this sub-watershed is also influenced by reservoir levels in Woodruff Narrow Reservoir. The primary land uses along the Bear River include agriculture and irrigation diversions and return flows. A review of aerial imagery indicates that channel enlargement, lateral accretion, and oxbow cutoffs have occurred. The Bear River also has direct channel impacts from alteration from woody plants to grass/forb communities, installation of diversion dams, and confinement from road crossings. The main stem of the Bear River meets the criteria for advancement to the RRISSC.

A review of aerial imagery in the upland areas of this sub-watershed does not indicate that any erosional processes are occurring that warrant advancement to the RRISSC. Additionally, sediment sources in upland areas are isolated from the Bear River by irrigation canals, which intercept flows and divert them into Woodruff Narrows Reservoir.

## 2.8. Selection of Sub-Watersheds and Reaches for Further Assessment (Step 15)

The information from steps 1 through 14 was used to document the guidance criteria and analysis for hill slope, hydrologic, and channel processes to determine which sub-watersheds could require a more detailed assessment. The guidance criteria are summarized below in Table 2-3 for each process discussed in section 2.5. The primary criteria for advancement to the RRISSC-level assessment were stream flow changes, channel processes, and direct channel impacts, with very little mass and surface erosion identified. In summary, the following 11 sub-watersheds and reaches were selected for further assessment:

1. Stillwater Fork (main stem)
2. East Fork Bear River (main stem)
3. Cottonwood Creek-Mill Creek
4. Willow Creek-Bear River
5. Lower Sulphur Creek (main stem downstream of Sulphur Creek Reservoir)
6. Duncomb Hollow-Bear River (main stem and east of City Ditch)
7. Lower Yellow Creek (downstream of Barker Reservoir and unnamed Reservoir on Sage Creek)
8. Upper Wasatch (main stem)
9. Lower Wasatch (main stem)
10. Bear River-Fowkes Canyon Creek (main stem, Red Willow Creek, and Dry Canyon)
11. Whitney Canyon Creek-Bear River (main channel)

**Table 2.3**. Evaluation and Summary of Guidance Criteria for Selection of Sub-Watersheds to Proceed to RRISSC or to Exclude from Further Assessment. Applicable Selection Criteria are Displayed for each Sub-Watershed

| **Watershed (HUC10)** | **Sub-Watershed (HUC12) /Reach Name** | **Step 7: Surface Erosion** | | **Step 8: Mass Erosion** | | **Step 10: Stream Flow Change** | | **Step 11: Channel Processes** | | **Step 12: Direct Channel Impacts** | | **Step 15: Selection for Further Assessment** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Selected Guidance Criterion Number (section 2.6.3)*** | **Reason for Exclusion** | **Selected Guidance Criterion Number (section 2.6.4)*** | **Reason for Exclusion** | **Selected Guidance Criterion Number (section 2.6.6)*** | **Reason for Exclusion** | **Selected Guidance Criterion Number (section 2.6.7)*** | **Reason for Exclusion** | **Selected Guidance Criterion Number (section 2.6.8)*** | **Reason for Exclusion** | **Satisfies Criteria for Advancement to RRISSC†** |
| Stillwater Fork-Bear River | West Fork Bear River | | NE | | NE | | NE | | NE | | NE | No |
| | Hayden Fork | | NE | | NE | | NE | | NE | | NE | No |
| | Stillwater Fork (headwaters) | | NE | | NE | | NE | | NE | | NE | No |
| | Stillwater Fork (main stem) | | NE | | NE | | NE | 4, | | | NE | Yes |
| | East Fork Bear River (headwaters) | | NE | | NE | | NE | | NE | | NE | No |
| | East Fork Bear River (main stem) | | NE | | NE | 1, 3 | | 4, 5 | | | NE | Yes |
| | Cottonwood Creek-Mill Creek | | NE | | NE | 1, 3, 4, 6 | | 4, 5 | | 2 | | Yes |
| | Willow Creek-Bear River | 2 | | | NE | 3, 4 | | | NE | 1, 2 | | Yes |
| Bear River-Sulphur Creek | Upper Sulphur Creek | | NE | | NE | 4 | Sulphur Creek Reservoir | 4, | Sulphur Creek Reservoir | 1, 2 | Sulphur Creek Reservoir | No |
| | LaChapelle Creek | | NE | | NE | 4 | Sulphur Creek Reservoir | 4 | Sulphur Creek Reservoir | 1, 2 | Sulphur Creek Reservoir | No |
| | Stowe Creek | | No recent evidence of erosion | | No recent evidence of erosion | | No recent evidence of erosion | | No recent evidence of erosion | | No recent evidence of erosion | No |
| | Lower Sulphur Creek (main stem downstream of Sulphur Creek Reservoir) | 2 | | | NE | 5, 6 | | 1, 3, 4, | | 1, 2 | | Yes |
| | Lower Sulphur Creek (outside of the main stem) | | NE | | NE | | NE | | NE | | NE | No |
| | Duncomb Hollow-Bear River (main stem and east of City Ditch) | 2 | | | NE | 4, 6 | | 4, 5, 6 | | 1, 2 | | Yes |
| | Duncomb Hollow-Bear River (uplands west of City Ditch) | | NE | | NE | | NE | | NE | | NE | No |

**Table 2.3**. Evaluation and Summary of Guidance Criteria for Selection of Sub-Watersheds to Proceed to RRISSC or to Exclude from Further Assessment. Applicable Selection Criteria are Displayed for each Sub-Watershed

| Watershed (HUC10) | Sub-Watershed (HUC12) /Reach Name | Step 7: Surface Erosion | | Step 8: Mass Erosion | | Step 10: Stream Flow Change | | Step 11: Channel Processes | | Step 12: Direct Channel Impacts | | Step 15: Selection for Further Assessment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Selected Guidance Criterion Number (section 2.6.3)* | Reason for Exclusion | Selected Guidance Criterion Number (section 2.6.4)* | Reason for Exclusion | Selected Guidance Criterion Number (section 2.6.6)* | Reason for Exclusion | Selected Guidance Criterion Number (section 2.6.7)* | Reason for Exclusion | Selected Guidance Criterion Number (section 2.6.8)* | Reason for Exclusion | Satisfies Criteria for Advancement to RRISSC† |
| Yellow Creek | Upper Yellow Creek | | NE | | NE | | NE | NE | | NE | | No |
| | Lower Yellow Creek (downstream of Barker Reservoir and Sage Creek) | 1, 2, 4 | | | NE | 4, 5, 6 | | 3, 4, 5, 6 | | | (1) (2) | Yes |
| | Lower Yellow Creek (upstream of Barker Reservoir and upstream of unnamed reservoir on Sage Creek) | | Barker Reservoir and unnamed reservoir on Sage Creek | | Barker Reservoir and unnamed reservoir on Sage Creek | | Barker Reservoir and unnamed reservoir on Sage Creek | | | Barker Reservoir and unnamed reservoir on Sage Creek | | Barker Reservoir and unnamed reservoir on Sage Creek |
| | Coyote Creek | | NE | | NE | | NE | | NE | | | No |
| | Upper Wasatch (main stem) | | NE | | NE | | NE | | NE | 1 | | Yes |
| | Upper Wasatch (outside of main stem) | | NE | | NE | | NE | | NE | | | No |
| | Lower Wasatch (main stem) | | NE | | NE | | NE | | NE | 1 | | Yes |
| | Lower Wasatch (outside of main stem) | | NE | | NE | | NE | | NE | | | No |
| Bear River-Pleasant Valley Creek | Pleasant Valley Creek | | NE | | NE | 1, 6 | Crompton and Painter Reservoirs<br>Irrigation diversions | | NE | | NE | No |
| | Bear River-Fowkes Canyon Creek (main stem, Red Willow Creek, and Dry Canyon) | | NE | | NE | 4, 6 | | 4, 5 | | 1, 2 | | Yes |
| | Bear River-Fowkes Canyon Creek (western uplands) | 2 | Irrigation canals<br>Intercept flow | | NE | 6 | Irrigation canals<br>Intercept flow | 4, 6 | Irrigation canals<br>Intercept flow | 1 | Irrigation canals<br>Intercept flow | No |
| | Bear River-Fowkes Canyon Creek (east of Tunnel Ditch including Fowkes Canyon Creek) | 1 | Irrigation canals<br>Intercept flow | | | 6 | Irrigation canals<br>Intercept flow | 6 | Irrigation canals<br>Intercept flow | | NE | No |
| | Whitney Canyon Creek-Bear River (main channel) | | NE | | NE | 4 | | 4 | | 1, 2 | | Yes |
| | Whitney Canyon Creek-Bear River (uplands) | | NE | | NE | | NE | | NE | | NE | No |

*Source*: The structure of this table is based on WARSSS Worksheet 1c (EPA 2008).

* Criteria based on overall review of the list in Table 2.1 and Table 2.2.

† Locations that meet one or more selection criteria satisfy guidelines for proceeding to the RRISSC assessment level.

*Note*: NE = No evidence available to support selection of guidance criteria.

# 3. RAPID RESOURCE INVENTORY FOR SEDIMENT AND STABILITY CONSEQUENCE

The RRISSC builds on the methods and results of the RLA phase to identify, prioritize, and evaluate sensitive landscapes, potentially unstable stream systems, and sediment-generating land use activities. The RRISSC uses a 22-step process that includes an inventory of the type, location, nature, and extent of land uses, and the sensitivity or erosion potential of the landscape and streams to highlight potential sediment sources (Figure 3.1). This section is organized by the steps outlined in Figure 3.1. To conduct this analysis, the watersheds identified by the RLA (refer to section 2.7) were divided into river reaches based on criteria such as HUC level, stream type, and valley type.

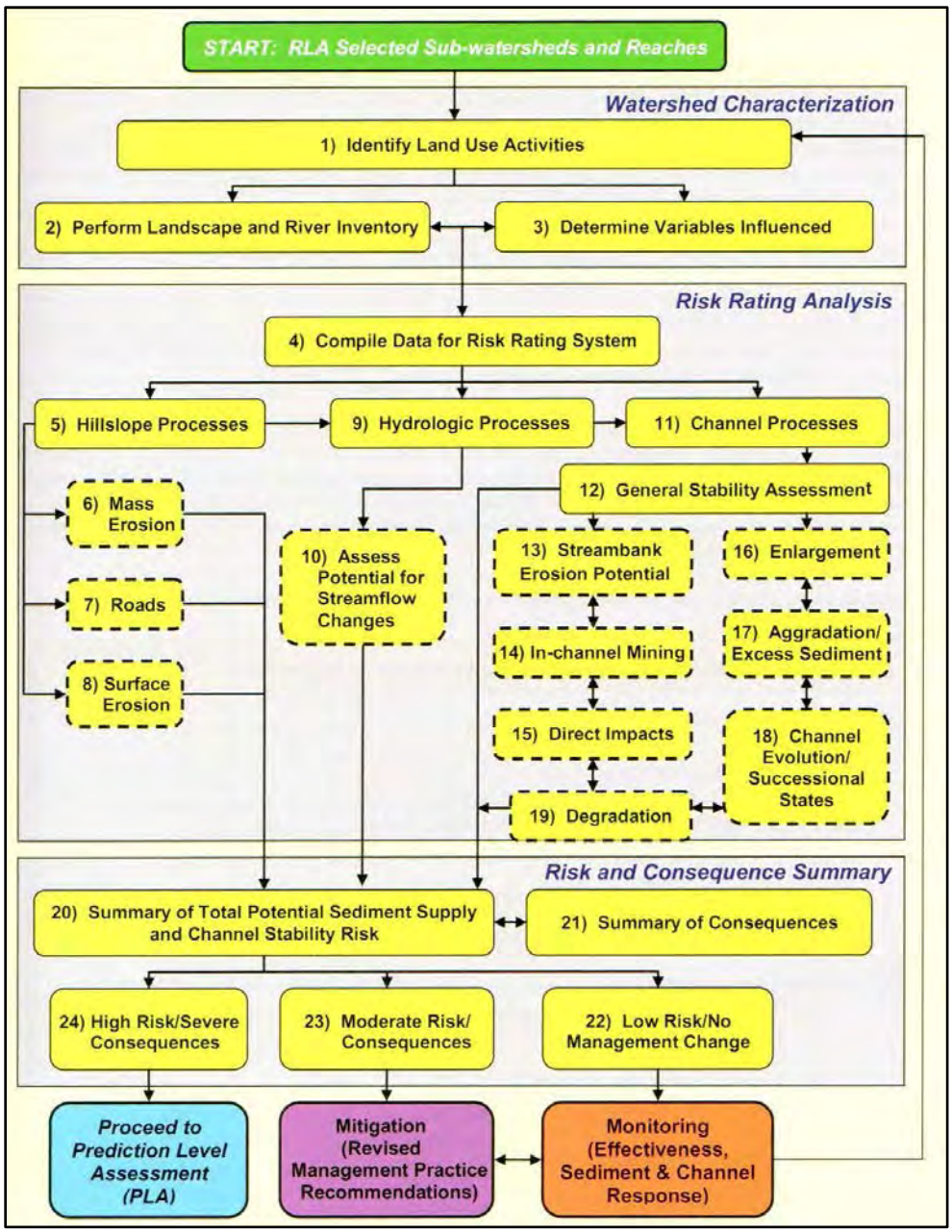



**Figure 3.1.** Procedural sequence of analysis for the RRISSC assessment (Rosgen 2009). Reprinted with permission from Wildland Hydrology.

## 3.1. Identify Land Use Activities, Perform Landscape and River Inventory, and Compile Data for Risk Rating System (Step 1 through 5)

Land use activities that are increasing the risk of erosional processes in each sub-watershed were identified by the RLA and are displayed in Table 2.3. Using this land use information, SWCA gathered existing data on roads, surface disturbance, mining, silviculture, agriculture, urban development, water management, and fires in each sub-watershed. These data were used in the steps described below.

## 3.2. Assess Mass Erosion Risk (Step 6)

No sub-watersheds met the guidance criteria for mass erosion in the RLA (see Table 2.3). As a result, all sub-watersheds received a very low risk rating for mass erosion (Table 3.1). Results of this data analysis are provided in the *Bear River WARSSS RLA and RRISC Worksheets* (WDEQ 2014: Worksheet 4-3).

## 3.3. Evaluate Road Impact Risk (Step 7)

Roads can directly introduce sediment from exposed cut banks, road fills, road surfaces, and ditch-lined erosion. Census Bureau TIGER roads data (U.S. Census Bureau 2012) were used to conduct an inventory of roads that requires information on the acres of surface disturbance of roads, number of stream crossings, slope position, and slope of the road. Electronic data on the age of the road, road surface, ditch lining, and vegetative condition of cut banks were not readily available for this analysis, and adjustments for the construction and design of the road could not be made. Results of this data analysis are provided in the *Bear River WARSSS RLA and RRISC Worksheets* (WDEQ 2014: Worksheet 4-4). In all, 12 sub-watersheds received a moderate risk rating, indicating that a disproportionate source of sediment or channel stability problems could be associated with a particular road system, and site-specific mitigation may be required (Table 3.1). However, no sub-watersheds received a high or very high risk rating indicating that they are not required for further analysis (Table 3.1).

## 3.4. Determine Surface Erosion Risk (Step 8)

Accelerated erosion may occur from surface erosion processes due to exposed bare soil, compaction, fire, and poor conservation practices. In general, the Bear River watershed is snowmelt dominated, and the location of land use disturbances and soil compositions does not make the area a high surface erosion risk. Reaches within four sub-watersheds—Duncomb Hollow, Bear River-Fowkes, and Lower Yellow Creek, and Lower Sulphur Creek—met the advancement criteria for surface erosion based on the observations of surface erosion on steep slopes or close to drainageways. Further analysis of the surface erosion potential in these sub-watersheds indicated that the landscapes were stable and contained a very low to low sediment delivery potential (WDEQ 2014: Worksheet 4-5). No sub-watersheds are recommended for further assessments of surface erosion (Table 3.1).

## 3.5. Hydrologic Processes (Steps 9 and 10)

The RRISSC evaluates the potential for increased water yield and associated flow-related sediment increases. Rural watersheds are assessed in terms of percentage of the watershed in a modified vegetative condition, such as clear cuts, forest fires, or non-forested land cover types. Urban watersheds are evaluated for percentage of impervious areas. The higher the altered percentage, the higher the potential

for increased flow-related sediment supply due to channel enlargement and incision. Results of this analysis indicate that 13 of the river reaches exhibit a high or very high risk of flow-related sediment supply (Table 3.1; WDEQ 2014). Rural sub-watersheds, such as Cottonwood Creek-Mill Creek and East Fork Bear River have, had significant changes in vegetative communities as a result of forest fires. Duncomb Hollow-Bear River, an urban sub-watershed, has a high percentage of impervious surfaces, increasing the risk of flow-related sediment supply.

In eight of the river reaches analyzed, flows are regulated by diversions and reservoir releases. Information was not available on the percentage increase or decrease in bankfull discharge. As a result, no adjustments in rating were given for flow regulation (WDEQ 2014: Worksheet 4-6).

## 3.6. Channel Processes (Steps 11–13)

Channel processes are influenced by increased stream flow and changes to the dimension, pattern, and profile as a result of encroachment and direct disturbance. Riparian vegetation changes were assessed using the vegetation cover types in the National Land Cover Data (U.S. Geological Survey 2011). A riparian corridor width of 50 feet was assumed on streams for this analysis. Channel geometry measurements were not available for all reaches and could not be used in this assessment. Risk ratings based on stream type and vegetation composition of the riparian corridor were used to assess risks associated with stream bank erosion. Results of this analysis are provided in the *Bear River WARSSS RLA and RRISC Worksheets* (WDEQ 2014: Worksheet 4-7). Reaches receiving a rating of high or very high are recommended for further detailed analysis of stream bank erosion and channel stability. These include reaches in Bear River-Fowkes, Cottonwood Creek-Mill Creek, Duncomb Hollow-Bear River, Lower Sulphur Creek, and Lower Yellow Creek (Table 3.1).

## 3.7. In-channel Mining (Step 14)

No in-channel mining occurs within any sub-watersheds analyzed. As a result, all sub-watersheds received a very low risk rating (Table 3.1; WDEQ 2014: Worksheet 4-8).

## 3.8. Assess Direct Channel Impacts (Step 15)

Flood control, land drainage, emergency flood relief, vegetative conversions, heavy grazing pressure, livestock concentrations, straightening, levees, dredging, clearing vegetation, and other related “river engineering” can cause major instability and sediment problems. Within each sub-watershed identified by the RLA as “at risk of direct channel impacts,” the riparian vegetation change, direct channel disturbance, and length impacted by large wood debris were assessed. The length of riparian vegetation change was determined based on the length of stream with altered vegetation types based on GAP data. Finer-scale vegetation data were not available for the study area. Using aerial imagery available in ArcGIS, SWCA digitized areas throughout each sub-watershed where direct channel disturbance was evident, including channelization, confinement associated with road crossings, and stabilization of stream banks. No large woody debris impacts were observed within the Bear River within the aerial imagery available.

Based on this analysis, direct channel disturbance resulted in high or very high risk ratings within reaches in the Duncomb Hollow-Bear River, Lower Wasatch, Lower Yellow Creek, and Upper Wasatch sub-watershed (Table 3.1; WDEQ 2014: Worksheet 4-9). Riparian vegetation change, based on the remote sensing data available, was not a high risk factor for any sub-watershed analyzed.

## 3.9. Channel Enlargement Risk Potential (Step 16)

Enlargement relations are based on the susceptibility of streams to incise and/or widen at an accelerate rate due to changes in flow, clear water discharge, direct disturbance, and stream bank erosion. For this analysis, the overall risk rating for channel enlargement was gained by summing the individual ratings for step 10 stream flow changes (WDEQ 2014: Worksheet 4-6), step 13 stream bank erosion (WDEQ 2014: Worksheet 4-7), and step 15 direct channel impact (WDEQ 2014: Worksheet 4-9). Based on these results, Duncomb Hollow-Bear River (downstream of Evanston), Duncomb Hollow-Bear River/Evanston, and Lower Yellow Creek (I-80 and railroad section) are at a high risk of channel enlargement and require further detailed analysis (Table 3.1; WDEQ 2014: Worksheet 4-10).

## 3.10. Calculate Aggradation/Excess Sediment Risk (Step 17)

Excess sediment deposition and reduction in sediment competence and capacity due to increases in width/depth ratio or slope changes are often responsible for aggradation. For this analysis, sediment supply or hillslope risk rating was determined by summing the risk ratings for step 6 mass erosion (WDEQ 2014: Worksheet 4-3), step 7 roads (WDEQ 2014: Worksheet 4-4), and step 8 surface erosion risk (WDEQ 2014: Worksheet 4-5). Based on this analysis, no sub-watersheds are at risk of hill slope (sediment supply) processes (WDEQ 2014: Worksheet 4-11).

The channel response to excess sediment supply could not be assessed because representative and reference reach width and depth ratios were not available for this analysis. In addition, observational data on aggradation was not available. As a result, the final aggradation risk rating could not be obtained (Table 3.1; WDEQ 2014: Worksheet 4-11).

## 3.11. Determine Channel Evolution Potential (Step 18)

Following disturbance, streams will try to re-establish a dimension, pattern, and profile of the pre-disturbance morphology. Observations based on stream type, reference conditions, and successional stages of stream channel evolution were made within each river reach to determine the channel successional risk rating (Table 3.1; WDEQ 2014: Worksheet 4-5). Results of this analysis indicate that reaches in Duncomb Hollow-Bear River and Upper Wasatch are at high or very high risk of channel evolution, which could result in significant erosion of stream banks before the channel reaches a stable state.

## 3.12. Calculate Degradation Risk (Step 19)

Lowering of local baseflow level through channel incision becomes a major adverse impact to stream stability, sediment supply, and water a resource uses. Assessment of the risk of degradation was determined by assigning the highest risk rating associated with each river reach from step 10 stream flow changes (WDEQ 2014: Worksheet 4-6), step 14 in-channel mining (WDEQ 2014: Worksheet 4-2), step 18 channel evolution (WDEQ 2014: Worksheet 4-5), and step 15 direct channel impacts (WDEQ 2014: Worksheet 4-9 and 4-12). Information was not available on road drainage designs and the presence of “shot gun” culverts or other unstable designs (WDEQ 2014: Worksheet 4-13). A risk ratings worksheet for potential contraction scour, degradation, or channel incision due to culverts or bridges could not be completed due to lack of observational data (WDEQ 2014: Worksheet 4-12).

Based on these results, reaches within Cottonwood Creek-Mill Creek, Duncomb Hollow-Bear River, East Fork Bear River, Lower Yellow Creek, and Upper Wasatch are at high or very high risk for degradation and require further detailed analysis (Table 3.1; WDEQ 2014: Worksheet 4-12).

## 3.13. Summarize Total Potential Sediment and Stream Channel Stability Risk and Create Overall Risk Rating Summary (Step 20 and 21)

The completed RRISSC summary in Table 3.1 provides documentation of overall risk rating summaries by river reach. Not all reaches have the same rating for all variables. This summary helps prioritize the land uses and locations where mitigation may be needed based on risk. For reaches of high and very high risk, a more detailed assessment depending on risk and associated land values is recommended. The river reaches recommended for advancement to the PLA are in Table 3.2. The primary reasons for advancement to the PLA were due to changes in flow regimes, channel degradation, and bank erosion, with no significant mass or surface erosion identified.

**Table 3.1** Summary of Results of the RRISSC Assessment

| Location Code/River Reach I.D. | Geographic Location | | | | Stream Type Location | | | | | | | Processes Identified by Step for Advancement to PLA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Step 6: Mass Erosion (Worksheet 4-3) | Step 7: Roads (Worksheet 4-4) | Step 8: Surface Erosion (Worksheet 4-5) | Step 10: Stream Flow Changes (Worksheet 4-6) | Step 13: Stream Bank Erosion (Worksheet 4-7) | Step 14: In-Channel Mining (Worksheet 4-8) | Step 15: Direct Impacts (Worksheet 4-9) | Step 16: Enlargement (Worksheet 4-10) | Step 17: Aggradation/Excess Sediment (Worksheet 4-11) | Step 18: Channel Evolution/Succession States (Table 4-5) | Step 19: Degradation (Worksheet 4-12) | |
| Bear River-Fowkes (main stem) | VL (1) | M (3) | VL (1) | L (2) | H(4) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | 13 |
| Cottonwood Creek-Mill Creek (Carter Creek) | VL (1) | M (3) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| Cottonwood Creek-Mill Creek (Christmas Tree Creek) | VL (1) | M (3) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| Cottonwood Creek-Mill Creek (Cow Hollow) | VL (1) | L (2) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| Cottonwood Creek-Mill Creek (Deadman Creek) | VL (1) | M (3) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| Cottonwood Creek-Mill Creek (headwaters of Mill Creek) | VL (1) | M (3) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| Cottonwood Creek-Mill Creek (Lower Christmas Tree Creek) | VL (1) | L (2) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (Lower Mill Creek and eastern drainages) | VL (1) | L (1) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (McKenzie Creek) | VL (1) | L (2) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (Mid Mill Creek) | VL (1) | L (2) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (Mill Creek Between McKenzie Creek and North Fork Mill Creek) | VL (1) | L (2) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (Mill Creek up to McKenzie Creek) | VL (1) | L (2) | VL (1) | M (3) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | M(3) | |
| Cottonwood Creek-Mill Creek (North Fork Mill Creek) | VL (1) | M (3) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| Cottonwood Creek-Mill Creek (Plot Creek) | VL (1) | L (2) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| Cottonwood Creek-Mill Creek (tributary 1) | VL (1) | L (2) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (tributary 2) | VL (1) | L (2) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (tributary 3) | VL (1) | L (2) | VL (1) | VL (1) | L(2) | VL (1) | VL (1) | VL(1) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (tributary 4) | VL (1) | L (1) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek (tributary 5) | VL (1) | M (3) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Cottonwood Creek-Mill Creek/Upper Cottonwood Creek | VL (1) | L (2) | VL (1) | VL (1) | H(4) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | 13 |
| Duncomb Hollow-Bear River/Downstream of Evanston | VL (1) | L (2) | L (2) | VH (5) | H(4) | VL (1) | H (4) | H(4) | ND | L(2) | VH(5) | 10, 13, 15, 16, 19 |
| Duncomb Hollow-Bear | VL (1) | M (3) | L (2) | VH (5) | L(2) | VL (1) | L (2) | M(3) | ND | L(2) | VH(5) | 10, 19 |

**Table 3.1** Summary of Results of the RRISSC Assessment

| Location Code/River Reach I.D. | Geographic Location | | | | Stream Type Location | | | | | | | Processes Identified by Step for Advancement to PLA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Step 6: Mass Erosion (Worksheet 4-3) | Step 7: Roads (Worksheet 4-4) | Step 8: Surface Erosion (Worksheet 4-5) | Step 10: Stream Flow Changes (Worksheet 4-6) | Step 13: Stream Bank Erosion (Worksheet 4-7) | Step 14: In-Channel Mining (Worksheet 4-8) | Step 15: Direct Impacts (Worksheet 4-9) | Step 16: Enlargement (Worksheet 4-10) | Step 17: Aggradation/Excess Sediment (Worksheet 4-11) | Step 18: Channel Evolution/Succession States (Table 4-5) | Step 19: Degradation (Worksheet 4-12) | |
| River/Duncomb Creek | | | | | | | | | | | | |
| Duncomb Hollow-Bear River (Evanston) | VL (1) | L (2) | L (2) | VH (5) | M(3) | VL (1) | H (4) | H(4) | ND | L(2) | VH(5) | 10, 15, 16, 19 |
| Duncomb Hollow-Bear River (Evanston to Sulphur Creek) | VL (1) | L (2) | L (2) | L (2) | H(4) | VL (1) | VL (1) | L(2) | ND | H(4) | H(4) | 13, 18, 19 |
| Duncomb Hollow-Bear River (upstream of Sulphur Creek) | VL (1) | L (1) | VL (1) | VL (1) | H(4) | VL (1) | VL (1) | L(2) | ND | H(4) | H(4) | 13, 18, 19 |
| East Fork Bear River (Boundary Creek) | VL (1) | VL (1) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| East Fork Bear River (headwaters) | VL (1) | VL (1) | VL (1) | H (4) | M(3) | VL (1) | VL (1) | M(3) | ND | VL(1) | H(4) | 10, 19 |
| East Fork Bear River/Lily Lake | VL (1) | L (2) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | VL(1) | VH(5) | 10, 19 |
| East Fork Bear River (main stem 1) | VL (1) | L (2) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | H(4) | H(4) | 10, 19 |
| East Fork Bear River (main stem 2) | VL (1) | L (2) | VL (1) | H (4) | M(3) | VL (1) | VL (1) | M(3) | ND | H(4) | H(4) | 10, 18, 19 |
| East Fork Bear River (main stem 3) | VL (1) | M (3) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | H(4) | VH(5) | 10, 18 |
| East Fork Bear River (main stem 4) | VL (1) | L (2) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | M(3) | VH(5) | 10, 19 |
| East Fork Bear River (main stem 5) | VL (1) | M (3) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| East Fork Bear River (unnamed tributary 1) | VL (1) | L (1) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | H(4) | VH(5) | 10, 18, 19 |
| East Fork Bear River (unnamed tributary 2) | VL (1) | L (2) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| East Fork Bear River (unnamed tributary 3) | VL (1) | L (2) | VL (1) | VH (5) | M(3) | VL (1) | VL (1) | M(3) | ND | L(2) | VH(5) | 10, 19 |
| Lower Sulphur Creek (downstream of Sulphur Creek Reservoir) | VL (1) | L (2) | VL (1) | L (2) | VH(5) | VL (1) | VL (1) | M(3) | ND | M(3) | M(3) | 13 |
| Lower Wasatch (main stem) | VL (1) | VL (1) | VL (1) | VL (1) | L(2) | VL (1) | VH (5) | M(3) | ND | L(2) | VH(5) | 15, 19 |
| Lower Yellow Creek (downstream of Wasatch Creek) | VL (1) | L (1) | L (2) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | M(3) | M(3) | |
| Lower Yellow Creek (I-80 and railroad section) | VL (1) | L (2) | L (2) | H (4) | H(4) | VL (1) | H (4) | H(4) | ND | L(2) | H(4) | 10, 13, 15, 16 |
| Lower Yellow Creek (upstream of I-80) | VL (1) | L (1) | VL (1) | VL (1) | H(4) | VL (1) | VL (1) | L(2) | ND | M(3) | M(3) | 13 |
| Stillwater Fork (headwaters) | VL (1) | L (1) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Stillwater Fork (main fork) | VL (1) | VL (1) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Stillwater Fork (main stem 1) | VL (1) | M (3) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Stillwater Fork (main stem 2) | VL (1) | M (3) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Upper Wasatch (main stem) | VL (1) | L (2) | VL (1) | VL (1) | M(3) | VL (1) | VH (5) | M(3) | ND | VH(5) | VH(5) | 15, 18, 19 |
| Whitney Canyon Creek-Bear River (main stem) | VL (1) | L (1) | VL (1) | VL (1) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |
| Willow Creek-Bear River (Stillwater Fork to West Fork Bear River) | VL (1) | L (2) | VL (1) | L (2) | M(3) | VL (1) | VL (1) | L(2) | ND | L(2) | L(2) | |

*Notes*: Numbers in parentheses denote the following: 1 = very low; 2 = low; 3 = moderate; 4 = high; 5 = very high.

**Table 3.2.** River Reaches Advanced to the Prediction Level Assessment

| River Reach | Reasons for Advancement |
|---|---|
| Bear River-Fowkes (main stem) | Bank erosion |
| Cottonwood Creek-Mill Creek (Carter Creek) | Flow change, degradation |
| Cottonwood Creek-Mill Creek (Christmas Tree Creek) | Flow change, degradation |
| Cottonwood Creek-Mill Creek (Cow Hollow) | Flow change, degradation |
| Cottonwood Creek-Mill Creek (Deadman Creek) | Flow change, degradation |
| Cottonwood Creek-Mill Creek (Headwaters of Mill Creek) | Flow change, degradation |
| Cottonwood Creek-Mill Creek (North Fork Mill Creek) | Flow change, degradation |
| Cottonwood Creek-Mill Creek (Plot Creek) | Flow change, degradation |
| Cottonwood Creek-Mill Creek (Upper Cottonwood Creek) | Bank erosion |
| Duncomb Hollow-Bear River (Downstream of Evanston) | Flow change, bank erosion, direct channel impacts, channel enlargement, degradation |
| Duncomb Hollow-Bear River (Duncomb Creek) | Flow change, degradation |
| Duncomb Hollow-Bear River (Evanston) | Flow change, direct channel impacts, channel enlargement, degradation |
| Duncomb Hollow-Bear River (Evanston to Sulphur Creek) | Bank erosion, channel evolution, degradation |
| Duncomb Hollow-Bear River (Upstream of Sulphur Creek) | Bank erosion, channel evolution, degradation |
| East Fork Bear River (Boundary Creek) | Flow change, degradation |
| East Fork Bear River (headwaters) | Flow change, degradation |
| East Fork Bear River (Lily Lake) | Flow change, degradation |
| East Fork Bear River (main stem 1) | Flow change, degradation |
| East Fork Bear River (main stem 2) | Flow change, channel evolution, degradation |
| East Fork Bear River (main stem 3) | Flow change, channel evolution |
| East Fork Bear River (main stem 4) | Flow change, degradation |
| East Fork Bear River (main stem 5) | Flow change, degradation |
| East Fork Bear River (unnamed tributary 1) | Flow change, channel evolution, degradation |
| East Fork Bear River (unnamed tributary 2) | Flow change, degradation |
| East Fork Bear River (unnamed tributary 3) | Flow change, degradation |
| Lower Sulphur Creek (downstream of Sulphur Creek Reservoir) | Bank erosion |
| Lower Wasatch (main stem) | Direct channel impacts, degradation |
| Lower Yellow Creek (I-80 and railroad section) | Flow change, bank erosion, direct channel impacts, channel enlargement |
| Lower Yellow Creek (upstream of I-80) | Bank erosion |
| Upper Wasatch (main stem) | Direct channel impacts, channel evolution, degradation |

# 4. PREDICTION LEVEL ASSESSMENT

The PLA is the most detailed level of the WARSSS methodology. It is reserved for sub-watersheds and river reaches previously identified as being at high risk for sediment and/or as having river stability problems (Rosgen 2009). The PLA compares existing sediment delivery and channel stability to a reference reach condition typical of stable, natural land and stream systems through quantification of stream flows and sediment supply rates. Although the overall PLA has many steps involved, only the Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) step was used in this analysis. This is because the BANCS model estimates sediment supply from bank erosion, which was identified as the major source of sediment in the impaired segment of the Bear River (i.e., other sediment sources such as surface erosion were negligible in comparison). The BANCS model uses field survey data to create two indices, the bank erosion hazard index (BEHI) and near bank stress (NBS) index, from which stream bank erosion rates can be quantified.

## 4.1. Bank Erosion Hazard Index and Near Bank Stress

SWCA used the BEHI and NBS methodologies (Rosgen 2009) to quantify bank erosion of the Bear River and its tributaries. Bank characteristics and stream flow patterns were visually estimated during two field survey events: one from July 11 to 14, 2013, and one from September 5 to 6, 2013. Survey areas were selected to represent areas of high erosion, as predicted by the RRISSC within the Bear River, the Yellow River, and Sulphur Creek, described above in section 3. Additionally, survey areas were selected to represent major valley and stream types in these areas. Surveys were conducted only in reaches where landowner permissions were granted.

In all, SWCA surveyed 16 unique reaches for a total of 124,750 bank feet (Map 4.1; Table 4.1). Three reaches, totaling 32,915 bank feet, were surveyed on the Bear River upstream of the confluence with Sulphur Creek (Chalk Creek Road, Jackson-Larson, and Upstream Sulphur Creek). Three reaches on the Bear River were surveyed between the confluences of Sulphur and Yellow Creeks, totaling 46,323 bank feet (Upstream State Park, Downstream Evanston to Hayduk Bridge, and Millis), and two reaches were surveyed on the Bear River after the confluence with Yellow Creek for a total of 11,026 bank feet (Narrows and Martin Property). Two reaches, totaling 9,199 bank feet, were surveyed on Sulphur Creek below Sulphur Creek Reservoir (County Road 159 and County Road 75), and six reaches, totaling 25,287 bank feet, were surveyed on Yellow Creek below Barker Reservoir (County Road 111, Downstream of County Road 111, near the wastewater treatment plant, Hayduk Property, Yellow Creek Road 1, and Yellow Creek Road 2).

**Table 4.1.** NBS and BEHI Survey Length Summary

| Survey Area | Reach Name | Map 4.1 Identifier | Reach Length (feet) |
|---|---|---|---|
| Bear River upstream of the confluence with Sulphur Creek | Chalk Creek Road | Reach 1 | 3,341 |
| | Jackson-Larson | Reach 2 | 20,408 |
| | Upstream Sulphur Creek | Reach 3 | 9,166 |
| Sulphur Creek | County Road 75 | Reach 4 | 3,612 |
| | County Road 159 | Reach 5 | 5,587 |
| Bear River between the confluences of Sulphur and | Millis | Reach 6 | 11,370 |
| | Upstream State Park | Reach 7 | 11,105 |

**Table 4.1.** NBS and BEHI Survey Length Summary

| Survey Area | Reach Name | Map 4.1 Identifier | Reach Length (feet) |
|---|---|---|---|
| Yellow Creeks | Downstream Evanston to Hayduk Bridge | Reach 8 | 23,848 |
| Yellow Creek | County Road 111 | Reach 9 | 2,773 |
| | Downstream of County Road 111 | Reach 10 | 3,046 |
| | Near wastewater treatment plant | Reach 11 | 12,802 |
| | Hayduk Property | Reach 12 | 797 |
| | Yellow Creek Road 1 | Reach 13 | 3,840 |
| | Yellow Creek Road 2 | Reach 14 | 2,029 |
| Bear River downstream of Yellow Creek confluence | Narrows | Reach 15 | 6,166 |
| | Martin Property | Reach 16 | 4,860 |

Within each reach, SWCA identified up to 114 individual banks with unique characteristics. During the surveys, banks were either grouped together or broken out depending on the continuity of BEHI and NBS measurements. For example, if several continuous banks had identical or near-identical BEHI and NBS measurements, they would be grouped as one bank. However, if an 8-foot bank separated two nearly identical 3-foot banks, those three banks would be broken out as individual banks. Both bank sides were simultaneously surveyed with one surveyor on each side of the river taking measurements for the opposite side.

BEHI and NBS measurements were visually estimated. Surveyors calibrated each other so that individual estimates of bank characteristics were similar and associated variance in estimates was reduced. Bank survey measurements comprised study bank height (total height of bank in feet), bankfull height (height of high-water mark in feet), vegetation rooting depth (feet from soil surface), vegetation rooting density (percentage of bank covered in roots), bank angle (degrees from horizontal), surface protection (percentage of bank protected by rocks or vegetation), bank material (e.g., gravel, cobble, sand), and bank stratification (binary, stratified or not). These data were used to calculate BEHI scores for seven categories (study bank height to bankfull height ratio, root depth to study bank height ratio, weighted root density, bank angle, surface protection, bank material adjustment, and stratification adjustment), the sum of which (total score) was used to determine the BEHI rating. The BEHI rating is a qualitative description of the bank erosion potential and is described as very low, low, moderate, high, very high, or extreme. NBS ratings were taken in conjunction with bank measurements and have the same qualitative descriptors as BEHI ratings. NBS is an evaluation of the stress exerted by stream flow on the stream banks, so a very low NBS Rating indicates that the stream flow exerts little-to-no force on the bank, whereas an extreme rating would indicate that stream flow is nearly perpendicular to the bank (i.e., all stream power is directed at the bank). BEHI and NBS data collected during the field surveys are provided in an Excel file delivered to WDEQ (WDEQ 2014).

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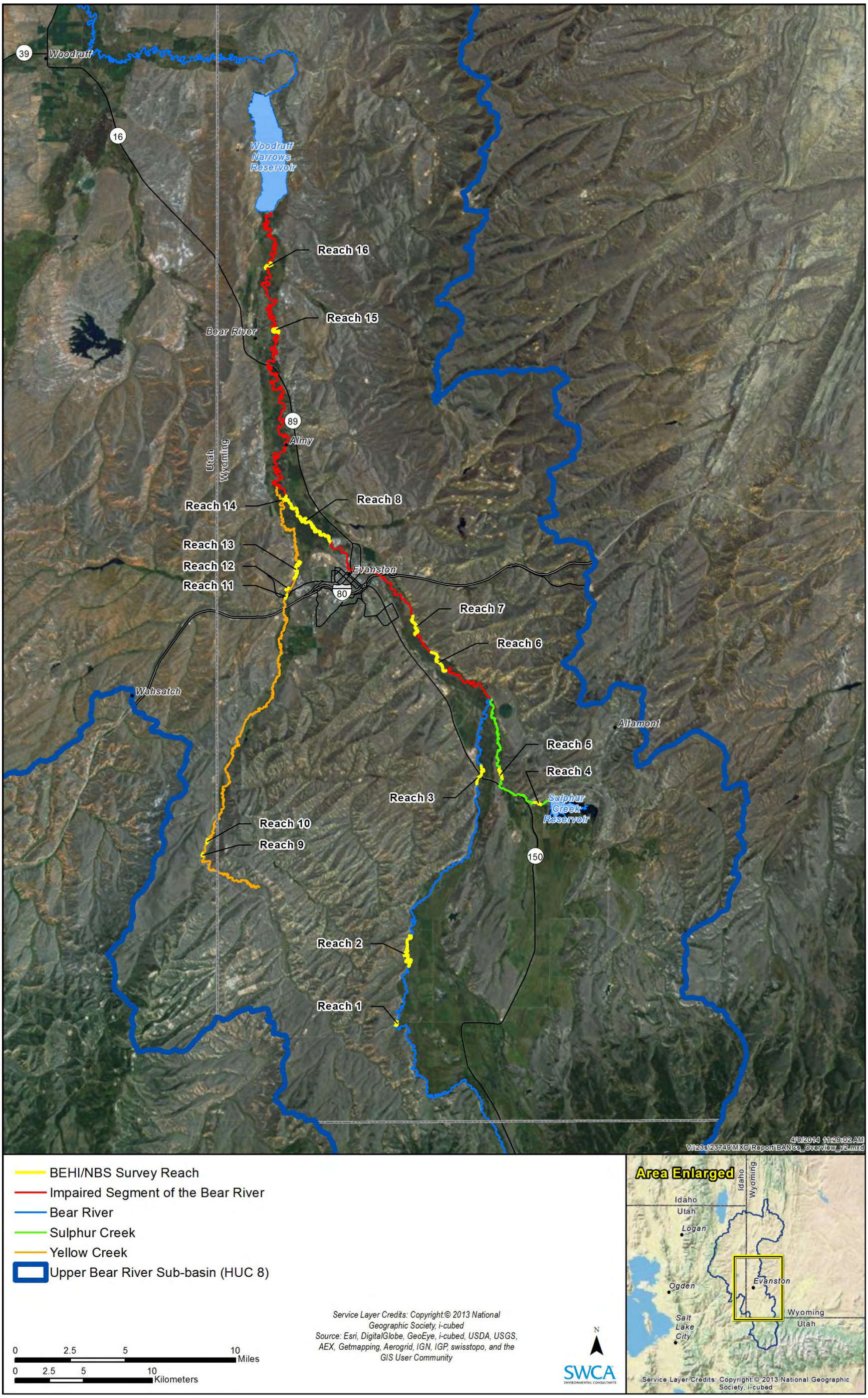


**Map 4.1.** Overview of BEHI and NBS survey locations on the Bear River, Sulphur Creek, and Yellow Creek, Wyoming, July 11–14, 2013, and September 5–6, 2013.

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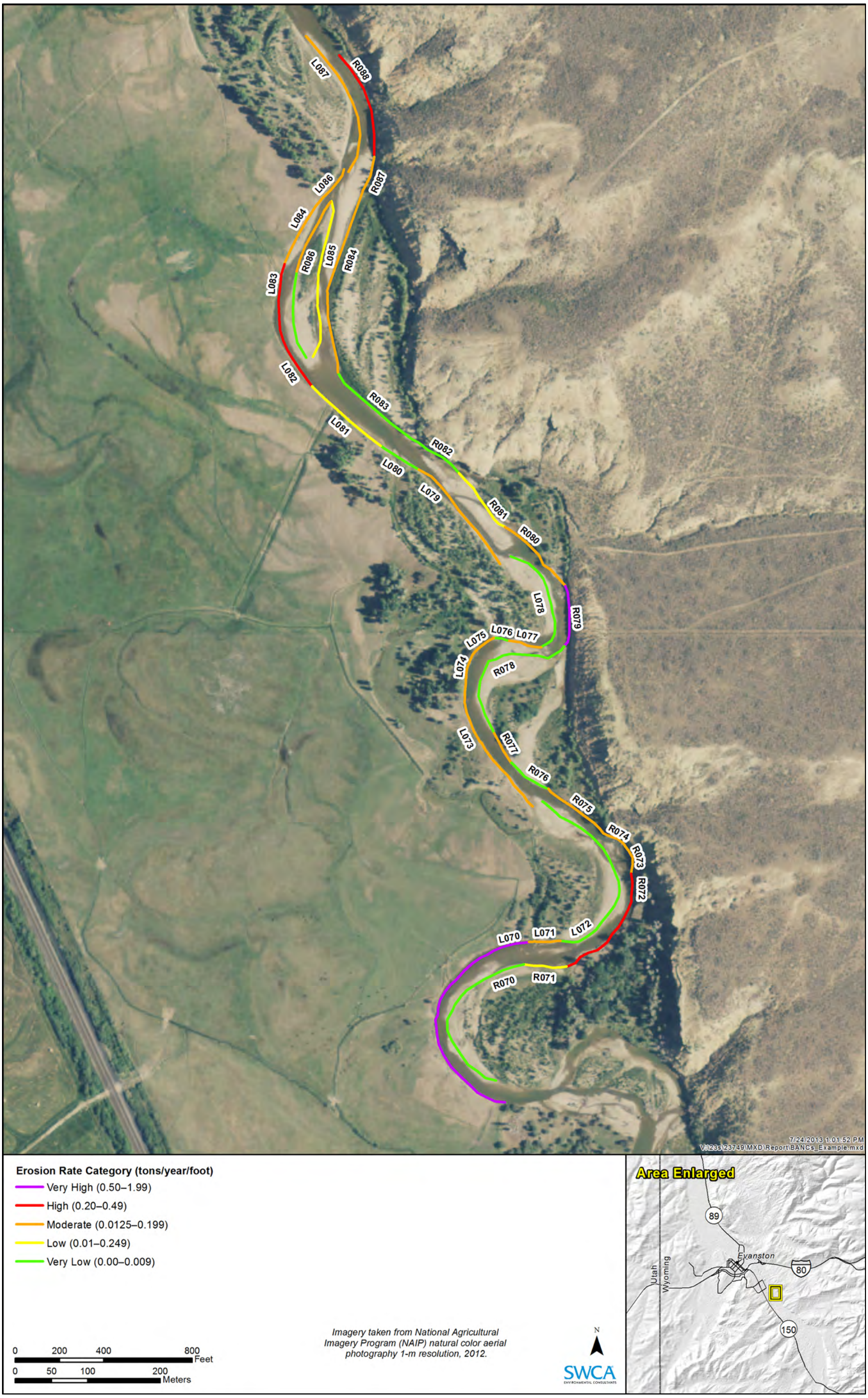
## 4.2. Bank Assessment for Non-Point Source Consequences of Sediment Model

The results of the BEHI and NBS surveys were used to estimate stream bank erosion rates for each survey reach by using the BANCS model (Rosgen 2009). This model uses the results from the BEHI and NBS study, as well as sediment rating curves, to estimate bank erosion rates. For this analysis, SWCA used a family of exponential sediment rating curves developed for Colorado streams in sedimentary geology (Rosgen 2009). The shape of the bank-specific sediment rating curve is determined by the bank-specific BEHI rating, and the NBS rating (qualitative ratings are assigned a number of 1 to 6) is used as the input to the exponential sediment function. The output of this function is a bank erosion rate in feet per year. This bank erosion rate was then converted to a length-normalized, mass-based reach erosion rate (tons per year per foot) by first multiplying by the total bank area (length by height) and the soil density (estimated at approximately 0.05 ton per cubic foot) to yield a bank-specific erosion rate in tons per year. These values were summed across similar valley and stream types within each survey reach to yield total erosion rates per valley and stream type by reach. Finally, these numbers were divided by the reach length associated with the specific valley and stream type to yield an erosion rate in tons/year/foot. A summary of these results is provided in Table 4.2 and a visual example of the output of this bank erosion analysis for the survey reach upstream of Bear River State Park is provided in Map 4.2.

**Table 4.2**. Summary of Annual Stream Bank Erosion Estimates for Survey Reaches, Stratified by Valley Type and Stream Type

| River | Sub-watershed (HUC 12) | BEHI/NBS Survey Reach | Valley Type | Stream Type | Total Bank Length (feet) | Bank Erosion (tons/year/feet) |
|---|---|---|---|---|---|---|
| Bear River | Willow Creek-Bear River | Chalk Creek Road | VI | C4 | 3,341 | 0.726 |
| | Duncomb Hollow-Bear River | Upstream Sulphur Creek | VI | C3 | 2,036 | 0.030 |
| | | | VIII | C3 | 6,114 | 0.059 |
| | | | | D3 | 1,015 | 0.090 |
| | | Upstream State Park | VI | C3 | 11,105 | 0.202 |
| | | Jackson-Larson | VI | C3 | 14,748 | 0.200 |
| | | | VIII | C3 | 5,661 | 0.135 |
| | | Millis | VI | C3 | 3,157 | 0.281 |
| | | | VIII | C3 | 8,213 | 0.091 |
| | | Downtown Evanston to Hayduk Bridge | VIII | C3 | 33,759 | 0.082 |
| | | | | D3 | 2,997 | 0.097 |
| | Bear River-Fowkes Canyon Creek | Narrows | VI | C4 | 6,166 | 0.198 |
| | Whitney Canyon Creek | Martin Property | VIII | C4 | 4,860 | 0.080 |
| Sulphur Creek | Lower Sulphur Creek | County Road 159 | VIII | C6 | 1,902 | 0.983 |
| | | | | F6 | 3,685 | 1.097 |
| | | County Road 75 | VI | B4 | 1,358 | 0.207 |
| | | | | C4 | 2,254 | 0.366 |
| Yellow Creek | Lower Yellow Creek | County Road 111 | VIII | C4 | 2,773 | 0.070 |
| | | Downstream of County Road 111 | VIII | C4 | 3,046 | 0.117 |
| | | Near wastewater treatment plant | VIII | C4 | 2,198 | 0.112 |
| | | Near wastewater treatment plant | VIII | C5 | 10,604 | 0.104 |
| | | Hayduk Property | VIII | C4 | 797 | 0.024 |
| | | Yellow Creek Road 1 | VIII | C4 | 3,840 | 0.766 |
| | | Yellow Creek Road 2 | VIII | C4 | 2,029 | 0.606 |




**Map 4.2.** Bank erosion rates (tons/year/foot) within a section of the survey reach on the Bear River Upstream of the State Park (41°14'16"N, 110°55'16"W).

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Annual stream bank erosion rates were highest in Sulphur Creek (0.207–1.097 ton/year/foot, average of 0.663 ton/year/foot) when compared to other survey areas (see Table 4.2). On average, Bear River had the lowest erosion rates (0.175 ton/year/foot) followed by Yellow Creek (0.257 ton/year/foot), though Chalk Creek Road and Yellow Creek Roads 1 and 2 were outliers of high erosion rates in Bear River and Yellow Creek, respectively (see Table 4.2). The lowest measured annual stream bank erosion rates were in the Bear River upstream of the confluence with Sulphur Creek (0.030–0.0200), not including the Chalk Creek Road reach. Annual stream bank erosion rates in the impaired section of the Bear River ranged from 0.080 to 0.198 ton/year/foot. Annual stream bank erosion rates in Yellow Creek ranged from 0.070 to 0.766 ton/year/foot. When considering these results, it is important to note that not all of the eroded bank material will be transported out of a stream or watershed as sediment. Bank material may be stored in depositional features within the stream channel and may not migrate to downstream reaches.

Bank erosion rates for each survey reach, stratified by valley type and stream type, were used to estimate the sediment load from bank erosion over the entire study area. These rates were then grouped into bank erosion rate categories based on the total distribution of observed rates (Table 4.3), and mapped (Map 5.1). When survey data were not available for each valley type or stream types, similar stream types were used as a surrogate erosion value.

**Table 4.3**. Erosion Rating Categories

| Category | Range of Erosion Rates (tons/year/feet) |
|---|---|
| Very low | 0.000–0.050 |
| Low | 0.051–0.100 |
| Moderate | 0.101–0.200 |
| High | 0.201–0.500 |
| Very high | 0.501–1.000 |
| Extreme | >1.000 |

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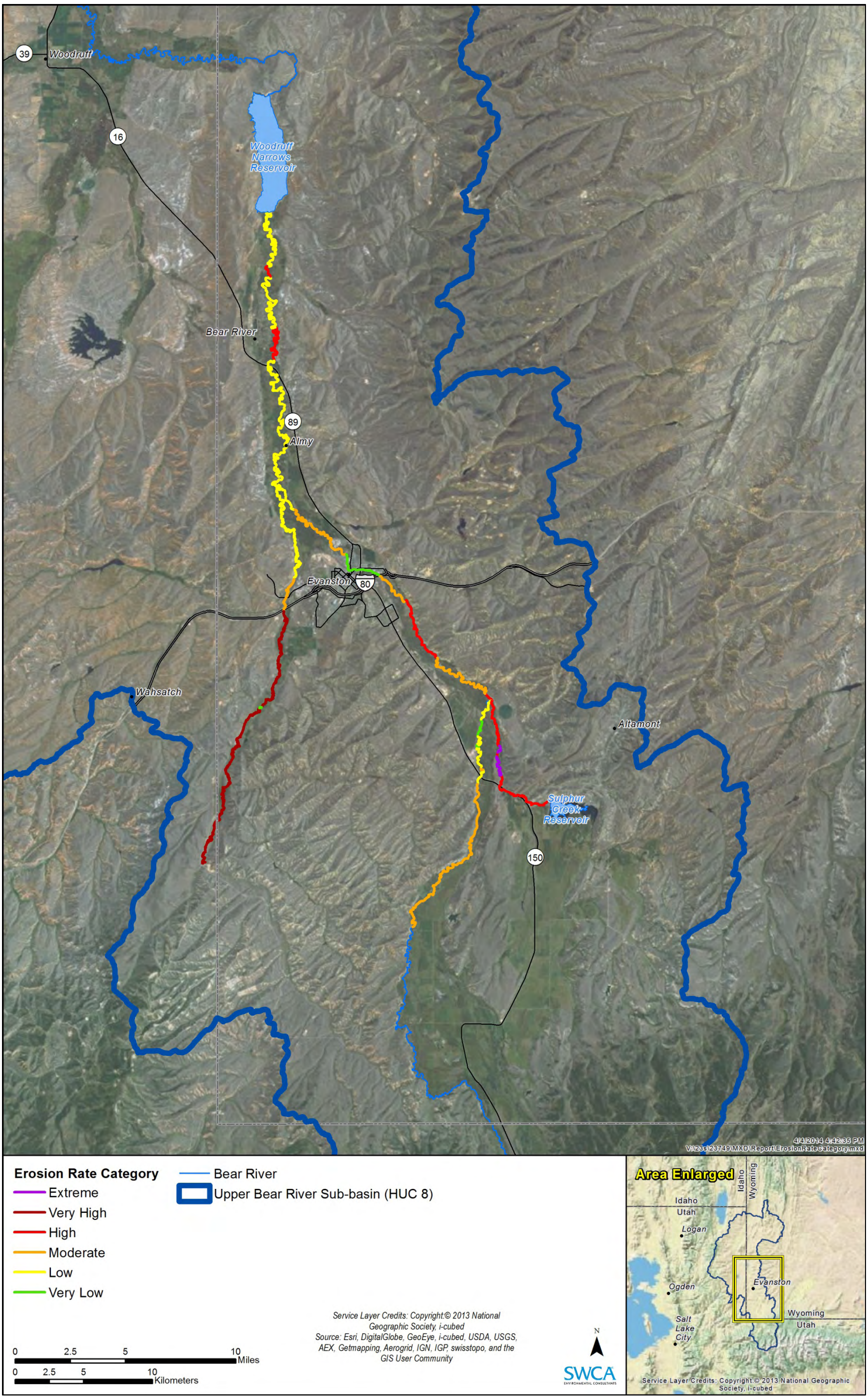


**Map 4.3.** Erosion categories for the study area.

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SWCA then classified the valley type and stream types within each sub-watershed and river using aerial imagery and topographic maps. SWCA intersected the valley and stream type classifications with the National Hydrography Dataset to calculate total length of each river by sub-watershed, valley type, and stream type. Finally, the calculated length-normalized bank erosion rate (see Table 4.2) was multiplied by the total length of river that was within the same sub-watershed, valley type, and stream type. Where appropriate, SWCA also broke the sediment load data down by Uinta County Conservation District sampling location where TSS data were available (Uinta County Conservation District monitoring stations BR1, BR2, BR3, BR4, and SC1).

The results of this analysis indicate that the highest rate of stream bank loss is occurring in Sulphur Creek and Yellow Creek (Table 4.4 and Table 4.5). It is estimated that 24,293 tons of sediment are eroding from the banks of Sulphur Creek per year (Table 4.4). Due to the total length of Yellow Creek, the total erosion rate for Yellow Creek is substantially higher than Sulphur Creek. It is estimated that 60,484 tons of sediment are eroding from the banks of Yellow Creek per year (Table 4.5). Again, it is important to note that not all of the eroded bank material will be transported out of Yellow Creek and Sulphur Creek as sediment. This is particularly true for Yellow Creek, which exhibits very little ability to transport sediment downstream to Bear River due to low flows (approximately 3 cubic feet per second at the confluence with Bear River).

Upstream of the impaired segment, it is estimated that 5,130 tons of sediment are eroding from the Bear River's bank per year (Table 4.6). Within the impaired segment of the Bear River, it is estimated that 19,740 tons of sediment are eroding from the banks per year (Table 4.7). Based on the BEHI/NBS survey results, the highest bank erosion rates in the impaired segment are occurring just downstream of the confluence with Sulphur Creek before passing through Evanston (average of 0.191 ton/year/foot) (Figure 4.1). However, when the total length of banks is used to estimate total erosion, approximately 9,522 tons of sediment are eroding from the banks upstream of Evanston per year compared to 15,348 tons per year downstream of Evanston (Table 4.7).

**Figure 4.1.** Survey bank on Sulphur Creek with an extreme BEHI rating and very high NBS rating.

**Table 4.4**. Stream Bank Erosion Rate for Sulphur Creek Downstream of Sulphur Creek Reservoir

| River Reach | Valley Type | Stream Type | Length of Stream (feet) | Sample Reach Total Erosion (tons/year/feet) | Total Stream Bank Erosion (tons/year) |
|---|---|---|---|---|---|
| Downstream of SC1 | VIII | C6 | 10,303 | 0.366 | 3,771 |
| Upstream of SC1 | VI | B4 | 3,587 | 0.207 | 742 |
| | | C4 | 9,107 | 0.366 | 3,333 |
| | VIII | B4* | 846 | 0.200 | 170 |
| | | C4* | 2,365 | 0.366 | 865 |
| | | C6 | 1,925 | 0.983 | 1,892 |
| | | F6 | 6,535 | 1.097 | 7,166 |
| **Total Upstream of SC1** | | | | | **14,168** |
| **Total for Sulphur Creek** | | | | | **17,938** |

* No BEHI/NBS surveys were conducted within this valley and stream type. Sample reach total erosion estimates from surveys conducted in Sulphur Creek within valley type VI were used as a surrogate erosion rate.

**Table 4.5**. Stream Bank Erosion Rate for Yellow Creek Downstream of Barker Reservoir

| River Reach | Valley Type | Stream Type | Length of Stream (feet) | Sample Reach Total Erosion (tons/year/feet) | Total Stream Bank Erosion (tons/year) |
|---|---|---|---|---|---|
| Downstream of Wasatch Creek | VIII | C4 | 31,492 | 0.068 | 2,139 |
| I-80 to Wasatch Creek | VIII | C4 | 7,934 | 0.093 | 741 |
| Barker Reservoir to I-80 | VI | C4 | 2,354 | 0.686 | 1,615 |
| | VIII | C4 | 81,579 | 0.686 | 55,973 |
| | | D5* | 682 | 0.022 | 15 |
| **Total for Yellow Creek** | | | | | **60,484** |

* No BEHI/NBS surveys were conducted within a D stream type. D channels are depositional areas, and bank erosion was assumed to be minimal. The lowest observed bank erosion rate in Yellow Creek was used for this stream type. Erosion rates from this stream type may be overestimated; however, the reach length is minimal and does not greatly affect the overall estimates.

**Table 4.6**. Stream Bank Erosion Rate for the Bear River within Duncomb Hollow-Bear River sub-watershed, Upstream of the Confluence with Sulphur Creek

| River Reach | Valley Type | Stream Type | Length of Stream (feet) | Sample Reach Total Erosion (tons/year/feet) | Total Stream Bank Erosion (tons/year) |
|---|---|---|---|---|---|
| Upstream of BR4 | VI | C3 | 547,312 | 0.115 | 842 |
| | VIII | C3 | 25,559 | 0.097 | 2,478 |
| | | D3 | 6,301 | 0.090 | 568 |
| BR4 Downstream to Sulphur Creek Confluence | VI | C3 | 5,126 | 0.030 | 154 |
| | VIII | C3 | 17,609 | 0.059 | 1,035 |
| | | D3 | 592 | 0.090 | 53 |
| **Total Upstream of BR4** | | | | | **3,888** |
| **Total Upstream of Impaired Segment** | | | | | **5,130** |

**Table 4.7**. Stream Bank Erosion Rate for the Impaired Segment of the Bear River

| Sub-watershed (HUC 12) | River Reach | Valley Type | Stream Type | Length of Stream (feet) | Sample Reach Total Erosion (tons/year/feet) | Total Stream Bank Erosion (tons/year) |
|---|---|---|---|---|---|---|
| Duncomb Hollow-Bear River | Sulphur Creek Confluence to BR 3 | VI | C3 | 16,809 | 0.242 | 4,061 |
| | | VIII | C3* | 3,637 | 0.091 | 330 |
| | BR3 to I-80 | VIII | C3* | 23,705 | 0.091 | 2,153 |
| | In the City of Evanston | VIII | C3† | 9,146 | 0.022 | 201 |
| | Evanston to sub-watershed Boundary | VIII | C3 | 19,146 | 0.110 | 2,104 |
| | | | D3 | 735 | 0.097 | 71 |
| Bear River-Fowkes | Sub-watershed Boundary to Yellow Creek | VIII | C3‡ | 7,386 | 0.080 | 593 |
| | Yellow Creek to BR 2 | VIII | C3‡ | 4,279 | 0.080 | 343 |
| | BR 2 downstream to sub-watershed boundary | VI | C4 | 12,938 | 0.198 | 2,562 |
| | | VIII | C3 | 44,964 | 0.080 | 3,607 |
| | | VIII | C4‡ | 23,554 | 0.080 | 1,890 |
| Whitney Canyon Creek | Sub-watershed boundary to BR 1 | VIII | C4‡ | 2,125 | 0.080 | 170 |
| | BR 1 to Reservoir | VIII | C4‡ | 21,188 | 0.080 | 1,700 |
| | | VI | C4‡ | 2,417 | 0.198 | 479 |
| **Sulphur Creek to BR 3** | | | | | | **9,333** |
| **BR 2 to BR 1** | | | | | | **10,407** |
| **Total Impaired Segment** | | | | | | **19,740** |

* No BEHI/NBS surveys were conducted within this valley and stream type. Sample reach total erosion estimates from surveys conducted in the Duncomb Hollow-Bear River sub-watershed for C3 stream type in a VI valley type were used as a surrogate erosion rate.

† No BEHI/NBS surveys were conducted within the city limits of Evanston. Bank erosion rates are assumed to be minimal due to extensive bank armoring.

‡ No BEHI/NBS surveys were conducted within this valley and stream type. Sample reach total erosion estimates from surveys conducted in the Bear River-Fowkes sub-watershed for C3/C4 stream type in a VIII valley type were used as a surrogate erosion rate.

# 5. CONCLUSIONS

Results from the RLA promoted 11 sub-watersheds to further RRISSC analysis, mainly based on evidence of changes to stream flow and direct channel impacts. The RRISSC broke out these sub-watersheds into reaches for further analysis and determined that 30 of these reaches should be promoted to a PLA for quantification of stream bank erosion through the BANCS model. The primary reasons for promoting reaches from the RRISSC to the PLA were due to changes in flow regimes, channel degradation, and bank erosion. Neither mass nor surface erosion was identified as a significant contributor to sediment supply in any of the reaches promoted from the RRISSC to the PLA. Results from the BANCS model indicate that the locations with the highest potential for sediment supply are Lower Sulphur Creek, Lower Yellow Creek, the impaired segment upstream of Bear River State Park, and a few areas of the impaired segment near the town of Bear River.

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