US Army Corps
of Engineers ®
Walla Walla District

Lower Boise River Interim Feasibility Study

Preliminary Evaluation of Arrowrock Site

October 2011

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ACRONYMS

Corps	U.S. Army Corps of Engineers
ESA	Endangered Species Act
ft	feet
IWRB	Idaho Water Resource Board
Reclamation	U.S. Bureau of Reclamation
RCC	roller compacted concrete
SHPO	State Historic Preservation Office
WRDA	Water Resources Development Act

1.0 INTRODUCTION

The U.S. Army Corps of Engineers (Corps) has been authorized to conduct a general investigation of the lower Boise River to review various water resource problems, needs, and opportunities. In May 2009, the Corps and the Idaho Water Resource Board (IWRB) entered into an agreement to initiate the first, or interim, phase of a two-phased feasibility study. The interim phase of the feasibility study is aimed at providing technical information regarding surface water storage potential in the basin, with a focus on water storage upstream of Lucky Peak Dam, and reducing flood risk in the lower Boise River downstream of Lucky Peak Dam. The Corps' study authorization is provided by Section 414, Water Resources Development Act (WRDA) of 1999, authorizing a feasibility study for flood control on the Boise River; and Section 4038, WRDA 2007, modifying the 1999 authority to include ecosystem restoration and water supply as project purposes.

From October 2009 through August 2010, the study team conducted a surface water storage screening analysis. The surface water storage screening analysis used information contained in the Bureau of Reclamation (Reclamation) *Boise/Payette Water Storage Assessment Report* (reference 1). The Reclamation study identified 12 sites worthy of further investigation. The Corps conducted a two-step screening evaluation. The first step involved narrowing the list of 12 sites to the six sites that best met future water supply needs and reduced flood risk downstream of Lucky Peak Dam. The second step compared and scored the remaining six sites for performance on six criteria, including future water demand, flood risk reduction, hydropower potential, a relative cost index, and social and environmental effects. The three top-ranked water storage and flood risk reduction sites included (1) replacement of Arrowrock Dam, (2) construction of a new dam at the Alexander Flats site, and (3) construction of a new dam at the Twin Springs site. The August 2010 *Water Storage Screening Analysis* (reference 2) document describes the screening criteria, the process used to score the surface water storage sites, and the analysis results.

The IWRB directed the Corps to conduct additional analysis of the Arrowrock site. The Arrowrock concept considered in the August 2010 *Water Storage Screening Analysis* assumed a new 368-foot roller compacted concrete (RCC) dam would be constructed immediately downstream of the existing Arrowrock Dam, increasing storage about 300,000 acre-feet. This report documents the additional analysis of this site.

2.0 PURPOSE OF REPORT

The purpose of this report is to examine the proposed Arrowrock site to

- Identify the most appropriate surface water storage concept for the site, i.e., raise the existing structure or construct a new facility downstream.

- Determine whether there are any major engineering or geological constraints that would make a dam raise or a new downstream dam at the Arrowrock site technically unfeasible or cost prohibitive.
- Identify issues for future study.

The analysis relied on existing data and field reconnaissance. The analysis described in this document consisted of these steps:

- Historical documents related to Arrowrock Dam were researched. Existing geological records and maps and construction documentation were reviewed.
- A field reconnaissance was conducted downstream of Arrowrock Dam in July 2011. Information was gathered on rock types, fracture orientation and spacing, topographic information, potential axes alignments, and other related site conditions. Geologic maps and documents were reviewed prior to and during the field investigation.
- Dam types were researched to identify design criteria for selecting a site and dam type for a potential new downstream dam. Raising the existing Arrowrock Dam was also evaluated.

3.0 CURRENT ARROWROCK DAM

There are three federal dams in the Boise River basin upstream of Boise, Idaho. Arrowrock Dam and Anderson Ranch Dam are operated by Reclamation, and Lucky Peak Dam, located downstream, is operated by the Corps. The three dams are operated as a system, primarily to provide irrigation water and flood risk reduction.

Arrowrock Dam was authorized by the Secretary of Interior on 6 January 1911 for the purpose of irrigation. The dam was constructed from 1911 to 1915. The original authorization included construction of a power plant downstream at the Boise River Diversion Dam. Electricity from this power plant was used for construction of Arrowrock Dam.

3.1 Site Selection History

Arrowrock Dam is located upstream from Lucky Peak Dam in the Boise National Forest (figures 11 and 12, pages 21 and 22). Before Arrowrock Dam was constructed, the locations of potential dam sites were studied from 1903 to 1910. Based on topography, the existing site, Arrowrock, and the Hell Gate site, three miles above Arrowrock, were evaluated. The predominant rock on both sites was granite; however, the granite at Arrowrock was decidedly stronger and more continuous. Both sites had basalt on the left abutments and it appeared the contact between basalt and granite was reasonably tight and solid (reference 3). However, at the Hell Gate site, the basalt was thicker and had more “subterranean openings” and “cavernous conditions.” The Arrowrock site was chosen because the basalt was less fractured, and the granite was considered more durable and continuous than at the Hell Gate site (reference 4). Additionally, the

Arrowrock site presented fewer construction difficulties and less cost for the same storage capacity (reference 5). The Arrowrock and Hell Gate sites were the only detailed site surveys found.

3.2 Site Geology

Surface geologic mapping of the site vicinity indicates the predominant site materials include granite and granodiorite of variable composition with a surficial cap of slopewash (overburden) (figure 1; reference 6). There are also isolated flow basalt exposures on slopes and alluvium in the channel bottoms. The granitic materials mapped near the site include Eocene biotite granite ("Tg") and hornblende-biotite granodiorite ("Tgd"). The overburden soils most often classify as silty sand and silty sandy gravel (per the Unified Soils Classification System). This material overlies granitic rocks that form the canyon walls and ranges in thickness from 1 to 7 feet. The alluvium exists as coarser, stream deposited materials in the river channel downstream of the dam, with finer-grained sediments deposited upstream of the dam in the reservoir (reference 7). Exposed basalt bedrock is mapped downstream of Arrowrock Dam. The materials are mapped as "Basalt of Gowen Terrace" ("Qtgb"). The field reconnaissance conducted on 28 July 2011 confirmed general mapped geologic conditions, and provided additional information about fractures, joint sets, outcrops, and site topography.

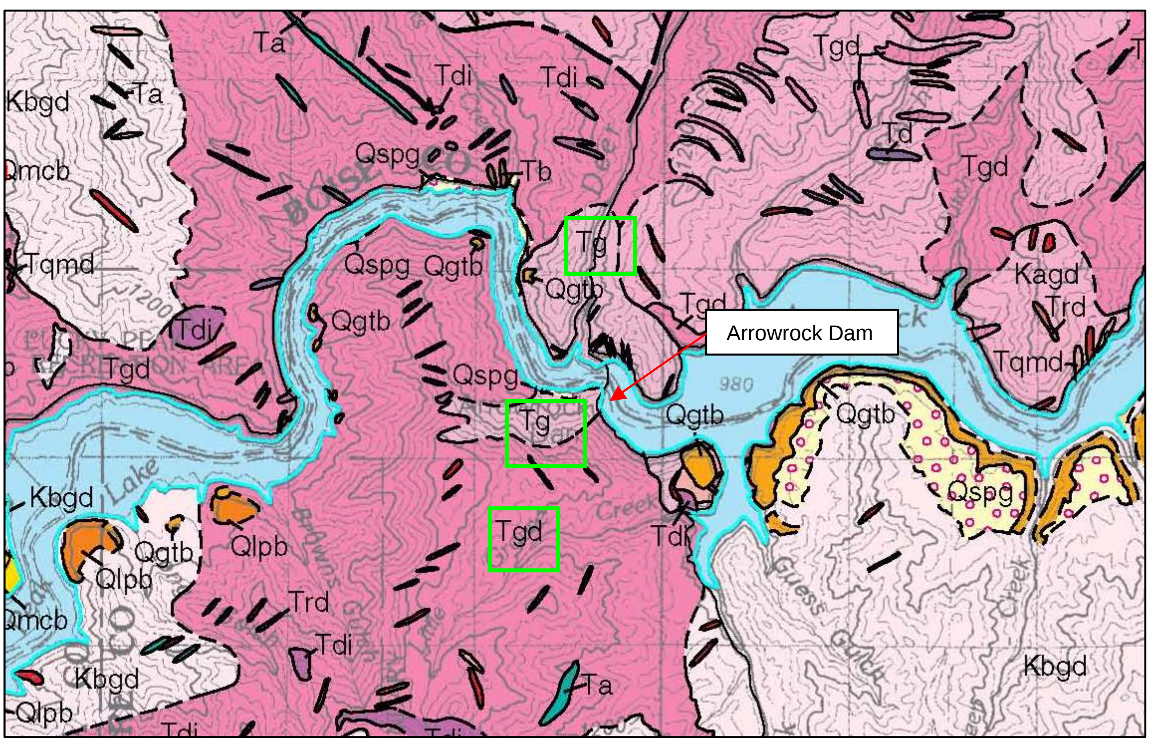

Figure 1. Geological Map

3.3 Project Information

Arrowrock Dam is a concrete arch gravity structure 350 feet high (exposed height is 294 feet), located in a narrow steep-walled canyon. The original dam construction was completed in 1915. During 1935 to 1937, the downstream face and the spillway structure were lined with new concrete. The dam was also raised 5-feet, increasing storage by 9,000 acre-feet, for a total storage capacity of 286,600 acre-feet. See table 1 (references 8 and 9).

Table 1. Arrowrock Dam Information

Dam Type	concrete gravity arch
Original Construction	1911-1915
Revised Capacity, as of 1997	272,200 acre-feet
Elevation, top of dam	3216 feet (ft)
Elevation, bottom of dam	2866 ft
Vertical Difference	350 ft
Reservoir Length	17 miles
Reservoir Area	3000 acres
High Tailrace Elevation	3055 ft
Low Tailrace Elevation	2958 ft

A 1997 sediment survey of Arrowrock Reservoir determined sediment behind the dam was 30 feet deep (elevation of 2987.4-feet). Based on the sedimentation survey, the revised reservoir capacity was estimated to be 272,200 acre-feet (active 271,700 acre-feet) (references 8 and 10). Foundation and abutment seepage conditions are considered acceptable (reference 11).

During construction, a diversion tunnel was constructed in the left (south) abutment and in the granite rock (figure 2). The bottom and sides of the diversion tunnel were lined

Figure 2. Diversion Tunnel During Construction of Arrowrock Dam

with concrete. The diversion tunnel was plugged with concrete for a length of 190 feet under the dam section in December 1914 (references 4 and 12).

In 2003, ten of the 20 originally installed ensign valves, which regulate water flow through the dam, were replaced with clamshell gates. The remaining ensign valves are rarely used.

In 2010, dam modifications and maintenance were completed and the Arrowrock Hydroelectric Facility was brought on line. It continues to generate electricity. The hydropower facility diverts water from the downstream end of the outlet conduits from two of the ten clamshell gates, through two 58-inch diameter steel penstocks, to two 7.5-megawatt Francis turbine generating units, and then to a tailrace that discharges into Lucky Peak Lake. The hydropower facility electrical transmission infrastructure is connected to the Idaho Power Company system.

4.0 POTENTIAL WATER STORAGE CONCEPTS FOR ARROWROCK SITE

This analysis considered two potential surface water storage concepts at the Arrowrock site to provide water supply and flood risk reduction: 1) raise Arrowrock Dam, or 2) construct a new dam downstream of the existing dam. Two options (or sites) were considered for construction of a new downstream dam. The recognized advantages and disadvantages for each concept are summarized in table 3 (page 17).

4.1 Arrowrock Dam Raise

Raising the existing Arrowrock Dam by 74 feet would involve construction on the downstream face of the existing dam. See figure 3 (page 8) for an example section view. Aerial photographs and historical reports document that Arrowrock Dam is currently in the best possible location, with the protruding ridges allowing for a shorter axis length. The original geologist, W. O. Crosby, who surveyed the area stated,

> "It is this geologic condition that has determined the fortunate coincidence of the bold and massive ledges of granite rising precipitously from the north bank of the river to elevations of 3200 to 3300 feet with the long narrow spur or ridge jutting out from the mountain on the south, as if to dam the valley. In other words, these prominent relief features, which virtually make the dam site are the natural topographic expression . . ." (reference 3).

4.1.1 Dam Raise Option - Advantages

Raising Arrowrock Dam has a cost advantage over constructing a new dam downstream. A dam raise would require less construction material, as the volume of existing concrete comprising the dam is substantial, resulting in a significant construction cost savings. A dam raise may also offer some cost advantages for geologic exploration. The galleries and abutment for the existing dam could provide less costly access for drilling. It appears this potential cost advantage would be significant for preliminary or feasibility study explorations. The overall environmental impact would probably be less for a dam raise than a new dam as construction would occur in an area previously disturbed by construction. The dam raise option may also have less impact on Lucky Peak reservoir operations.

4.1.2 Dam Raise Option - Disadvantages

There are many uncertainties and associated cost risks associated with a raise of the existing Arrowrock Dam. Most of these issues can be addressed or mitigated, as evidenced by successful dam raises at other projects. In general, the unknowns can be addressed by exploration and analyses. Sufficient exploration and evaluation should occur to evaluate these uncertainties and reduce potential cost risks.

Cost Risks Associated with Existing Dam

Unknowns attributable to the portion of the dam constructed in 1915 could substantially increase maintenance costs over time. Expensive measures could be required in the future if current safety requirements become more stringent. Examples of unknowns regarding the existing dam include:

- The existing dam was constructed using concrete with a high proportion of sand-cement. By 1935, the concrete on the downstream face of the structure showed deterioration due to climatic conditions. Repairs were required to reface the downstream face and spillway channel (reference 8). The current Arrowrock concrete is functioning as it was designed. There have been no recent tests to indicate otherwise. However, additional sampling and testing would be needed to verify concrete quality if a dam raise project was pursued. Resurfacing the downstream face may be needed depending on testing results.
- The concrete mix design, aggregate quality and gradation, the handling and placement of the concrete, and many other aspects of concrete construction probably do not meet modern requirements. Arrowrock Dam was not constructed with air-entrained concrete, so the durability of the existing concrete is less than modern air-entrained concrete. Reclamation personnel have indicated that concrete maintenance concerns have been associated with surface durability issues as opposed to concrete strength.
- Foundation preparation likely does not meet modern requirements.
- The existing water passage elements of the dam will need to be evaluated and incorporated into the new structure, or abandoned and replaced.
- While much exploration information may be available, considerable additional exploration would be needed to meet current exploration requirements and to fully characterize the connection of the dam to the surrounding bedrock.
- The original bypass tunnel on the left abutment was plugged with concrete. It is likely that remnants of the tunnel remain.
- The existing spillway would need to be relocated.
- A new, taller dam project would likely include construction of large, modern powerhouse with multiple units that take full advantage of available hydropower potential. The existing dam intake works and passages may require substantial

rehabilitation or reconstruction to make provision for large modern generation equipment

Cost Risks Associated with Existing Site

The unknowns regarding the existing site represent construction cost risk issues. While the cost risk associated with the various issues may be large, the actual cost for any particular issue will depend heavily on construction methods, schedule, or other aspects of construction that can often be controlled. Examples of unknowns regarding the existing site include:

- Excavations for the dam extend at least 90-feet below the river surface, which is well below the existing Lucky Peak reservoir elevation. Excavations downstream of the existing dam would require a downstream cofferdam and prolonged lowering of the Lucky Peak reservoir, or a combination of the two.
- The existing dam takes up the full length of the narrow draw created by the local topography. The downstream portion of the new dam would need a longer dam axis than the existing dam.
- The topography immediately downstream of the existing dam is not symmetrical, which is not desirable for concrete structures.

Cost Risks Associated with Boise River System Operations

Unknowns related to construction impacts on reservoir operations represent potential cost risk. Construction would need to occur in a manner that avoids or minimizes negative impacts to water users and flood risk reduction currently provided by system operations. Examples of unknowns regarding system operation impacts include:

- It may be necessary to lower Arrowrock Reservoir to construct a bypass tunnel, or to relocate or replace the existing ensign valves or clamshell gates.
- It may be necessary to draw down the Lucky Peak reservoir or build a large downstream cofferdam for foundation excavations.
- The Arrowrock Hydroelectric Facility operation may need to be stopped at the beginning of construction.

Additional operational analyses are required to determine the magnitude of any effects.

4.1.3 Dam Raise Project Examples

Even with the above mentioned disadvantages, dam raising projects have recently occurred in the United States. The below examples are similar to an Arrowrock Dam raise concept. Discussions with engineers who worked on these projects would benefit future study of a possible raise of Arrowrock Dam.

San Vicente Dam Raise
San Vicente Dam, located near San Diego, California, was constructed in 1944 at a height of 220 feet. A project to raise the dam 117 feet is ongoing and is scheduled for

completion in 2015. To prepare the dam to receive new concrete, the contractor excavated down to the existing dam's foundation, filled crevices with concrete, and installed a new pipeline through the existing dam. The contractor removed about 2 inches of downstream surface of the dam to create a good bonding surface for the new concrete. Then massive quantities of RCC will be placed to raise the dam. See figure 3 for cross section view (reference 13).

Theodore Roosevelt Dam Raise
Theodore Roosevelt Dam is a Reclamation project located 76 miles northeast of Phoenix, Arizona. The dam was completed in 1911 at a height of 280 feet. From 1989 to 1996, Reclamation raised the dam by 77 feet. The dam raise modified the original cyclopean, rubble-masonry, thick-arch structure to a concrete-gravity arch (reference 14). The dam's age and type is very similar to Arrowrock Dam.

4.2 New Dam Site Downstream of Arrowrock Dam (Options 1 and 2)

On 28 July 2011, the Corps conducted field reconnaissance to investigate a possible new dam site downstream of Arrowrock Dam. The purpose of the field investigation was to understand the geologic and topographic conditions and identify specific locations for a downstream dam option. Two potential sites were explored immediately downstream of Arrowrock Dam (Options 1 and 2) (figures 13 through 15, pages 23 through 25). Option 1 is upstream of Option 2. Both sites were chosen based on topography, which is dominated by steep canyon walls on each side of the river. (See figures 4 through 5). Table 2 lists dimensional information related to the two proposed sites.

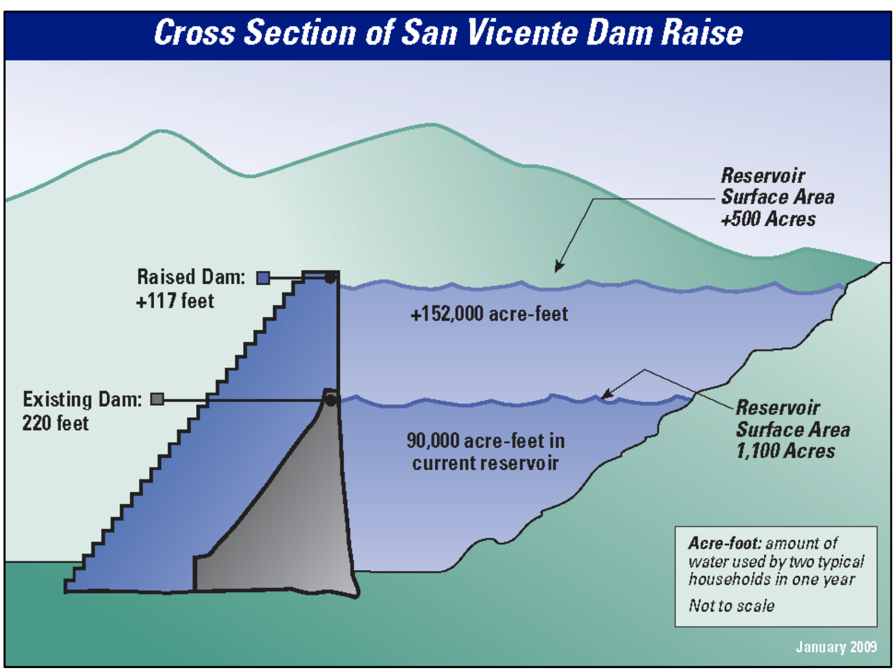

Figure 3. San Vicente Dam Raise

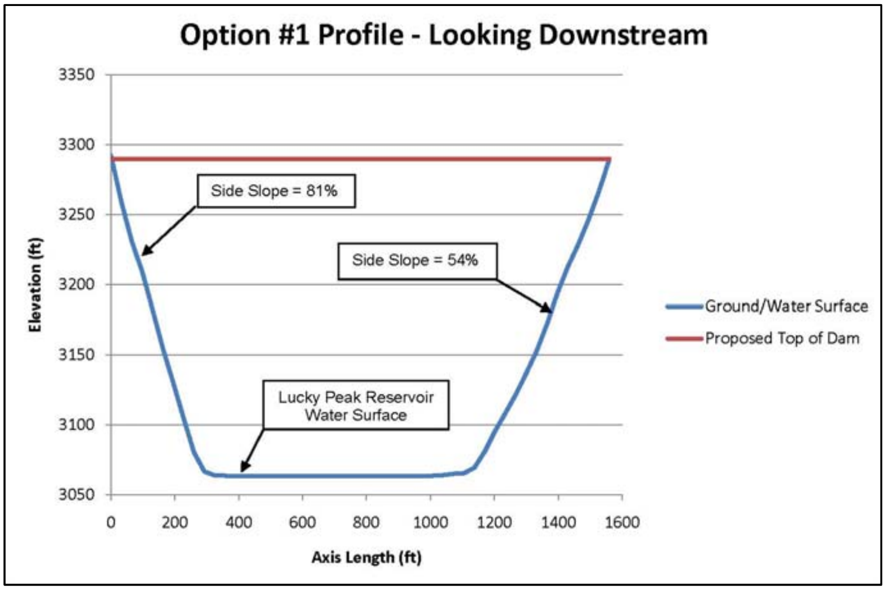

Figure 4. New Dam, Option 1 Profile

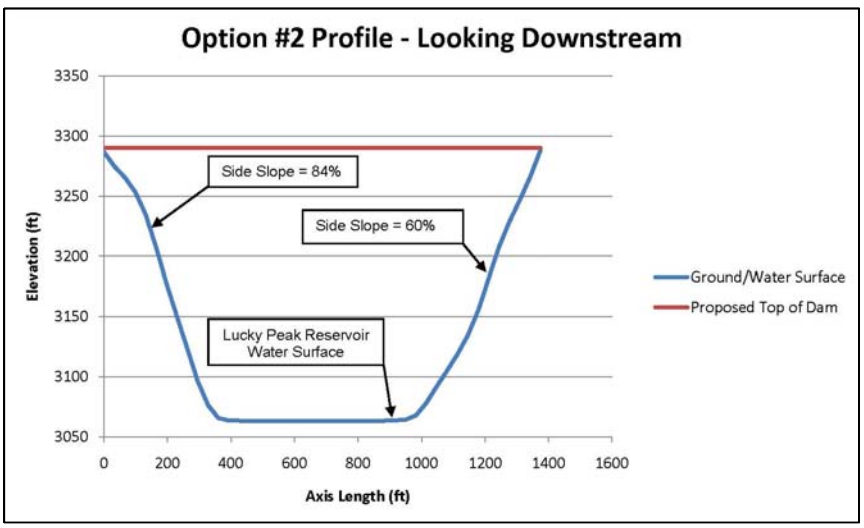

Figure 5. New Dam, Option 2 Profile

Table 2. New Dam Dimensional Information

	Option 1	**Option 2**
Top of Dam Elevation	3290	3290
Bottom of Dam Elevation (estimate)	2850	2844
Vertical Difference (ft)	440	446
Axis Length (ft)	1563	1379+ depending on location of right abutment
Length to Height Ratio	3.6	3.1+
Distance From Arrowrock Dam (ft)	2650	4600

The July 2011 field reconnaissance observed that both sites (Option 1 and 2) have granitic bedrock dipping upstream with similar fracture patterns and spacing. The proposed abutments would be located on small ridges where the bedrock is partially exposed. The bedrock type is granite or coarse-grained igneous rock of similar composition and is similar in character to the foundation material at the existing Arrowrock site. It appears minimal excavation of overburden would be required to reach underlying solid granite. The granite has an easterly or upstream dip of about 50°, which would be normal to the induced loading stress directions of the proposed structure (figures 6 through 8). The major fracture trend is approximately N60°E in strike, thereby reducing the tendency for a sliding or overturning failure along primary fracture planes. The granite has three additional sets of less obvious fracture patterns, and the combination of fracture directions gives the surface appearance of very close to moderate fracture spacing.

Sites further downstream were briefly examined, but were deemed less desirable. A dam located in these areas would require inundation of Macks Creek, 5 Mile Flat, and about one extra mile of Elmore County Road (see figure 15, page 25). The average dam axis length would be about 1860 feet, which is substantially longer than the two options listed above. The further the dam is downstream, the greater the vertical difference required to maintain an elevation of 3290' necessary to provide an additional 317,000 acre-feet of proposed storage.

Figure 6. North Side of River

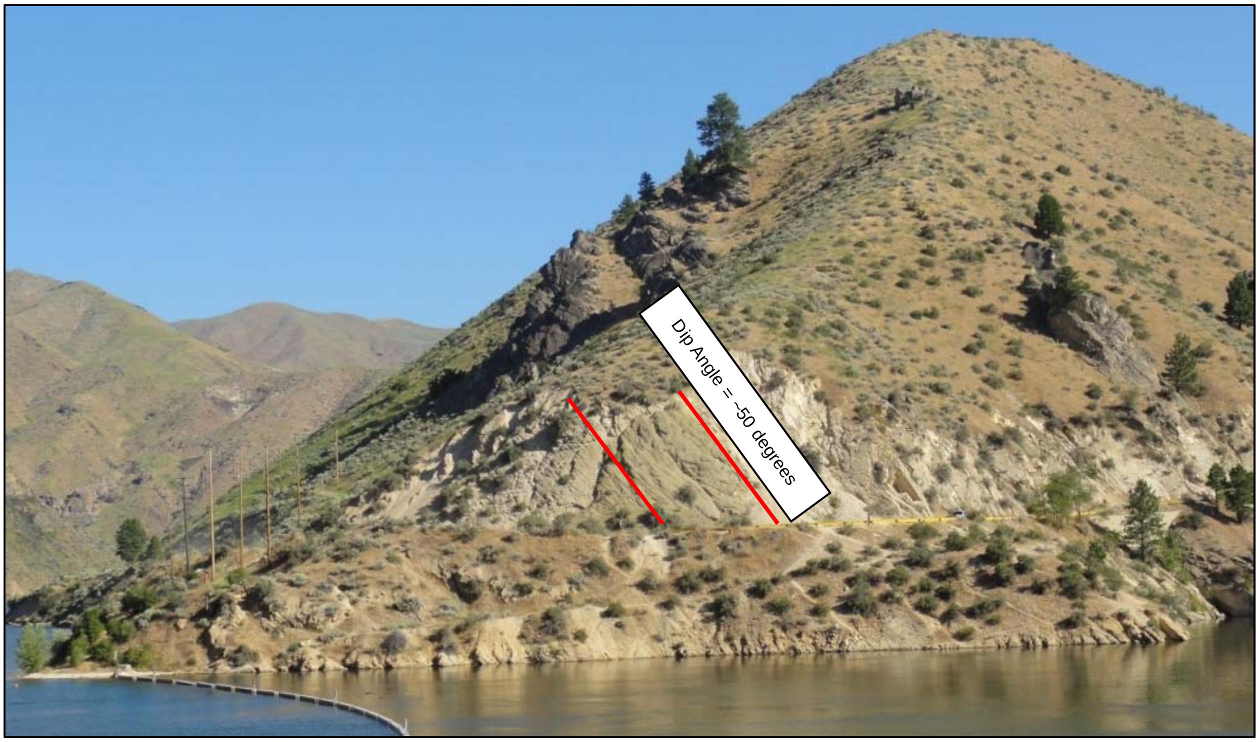

Figure 7. North Side of River

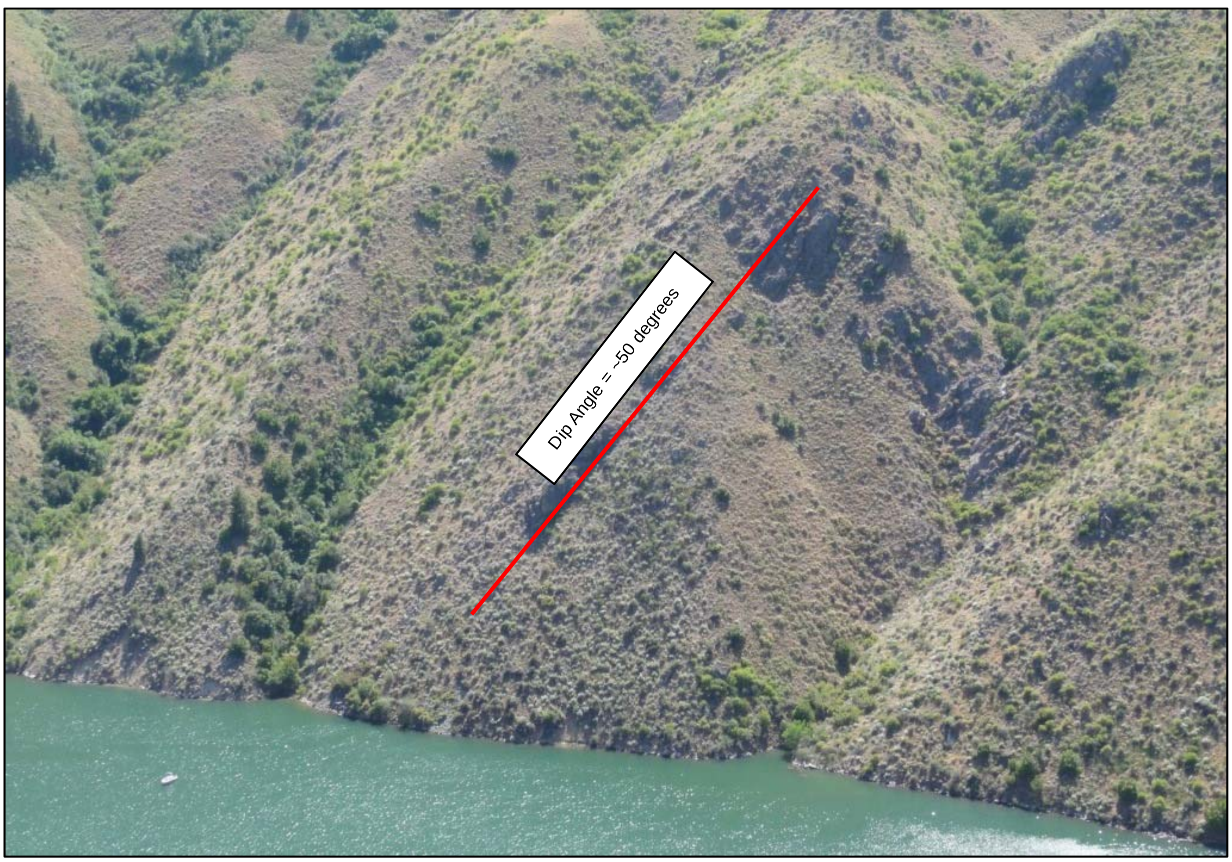

Figure 8. South Side of River

4.2.1 Recommended Site

Of the two sites considered, Option 1 is recommended as a preferred location for a new dam based on geological information and its location further upstream. Option 2 is located further downstream which would require a greater vertical difference, top to bottom, to achieve the required pool elevation of 3290'. A larger vertical difference would require a taller dam and more construction material. Option 2 is also anticipated to have greater potential impacts to the Lucky Peak reservoir pool, because the reservoir pool would have to be drawn down to a lower elevation to accommodate dam construction. Option 2 would also require a taller, downstream cofferdam than Option 1, resulting in greater construction costs.

Based on the surface geologic mapping of the site, and confirmed by field reconnaissance, Option 2 has basalt present on the right abutment of a proposed dam. Current practice would potentially dictate additional excavation at the Option 2 location to remove the intra-canyon basalt. The right abutment of the proposed dam could be located upstream from the basalt, but such placement would increase the length of the structure by several hundred feet for placement on granitic rock. Either modification will increase length and incur greater cost for Option 2. However, the basalt removed for Option 2 could provide some rock material for use in construction of the dam. It appears Option 1 offers less complicated geology.

Based on information from field reconnaissance and engineering judgment, Option 1 is considered the better choice. Several potential advantages and disadvantages associated with construction of a new dam at the Option 1 site were identified.

4.2.2 New Dam - Advantages

- A new dam would be constructed entirely of air-entrained concrete, which is more durable than non air-entrained concrete.
- Arrowrock Reservoir would not have to be lowered to conduct construction or repair activities upstream of Arrowrock Dam.
- A new dam would incorporate all modern design criteria and requirements that do not exist in Arrowrock Dam.
- The new dam site has steep, competent abutment slopes that are composed of granite, which should provide good foundation support for a new dam.

4.2.3 New Dam - Disadvantages

- Access and cost for exploration and analyses at the new dam site are more challenging than at the existing Arrowrock Dam site.
    - Site access and exploration for a new dam would require significant surface disturbance in previously undisturbed areas and exploration within the Lucky Peak reservoir pool.
    - The canyon is wider downstream of Arrowrock Dam. This wider section of canyon would require more construction material to build the dam.

- Lucky Peak reservoir would have to be lowered for a significant amount of time during construction. This would temporarily reduce the Lucky Peak reservoir capacity and negatively impact system operations, irrigation storage, and recreation.
- The existing Arrowrock Dam would need to be abandoned or demolished to ensure reservoir continuity. Notching, holing, and demolition would need to be considered. Full removal of the existing dam would make this concept cost prohibitive.
- Continued operation of the Arrowrock reservoir would require construction of a water passage to bypass the new construction.
- The new dam would require a new spillway.

4.2.4 Potential Dam Type

Three potential dam types were evaluated for the Option 1 site, including arch, embankment, and gravity. Based on this evaluation and existing available information, an RCC straight-axis gravity dam or arch dam appears to be the most suitable dam type for the Option 1 site. A summary of each dam type follows.

Arch Dam - This type of dam is a thin concrete structure constructed in an arc between narrow canyon walls. The constructed dam relies on its geometry to transfer hydrostatic (water pressure) loads to the foundation and abutments. These structures are sometimes curved vertically as well as horizontally, where narrow, symmetrical V-shaped canyons allow for the most efficient designs (reference 15). The topography of the existing Arrowrock site worked well with an arch dam design, although its configuration is not a classic arch dam. It is a curved concrete gravity dam. Traditionally, most of the arch dams in the United States have been constructed in canyon sites with length-height ratios of less than 4 to 1. The Option 1 site has a length/height ratio of 3.1 to 1.

Arch dams are constructed using conventional concrete, resulting in tremendous heat during curing, which increases construction time and requires special cooling measures. However, the total volume of this type of structure can be substantially less than other types of dams. If the availability of materials is severely restricted, it may be worthwhile to revisit this type of dam.

Embankment Dams - The two principal types of embankment dams are earth and rock-fill dams, depending on the predominant fill material used. Some generalized sections of rock-fill dams are shown in figure 9 (reference 16). An earthen dam is composed of suitable soils obtained from borrow areas or required excavation, which is then compacted in layers by mechanical means. One advantage of an earth dam is that it can be adapted to a weak foundation, provided proper consideration is given to thorough foundation exploration, testing, and design (reference 16). A new dam at the Option 1 site would be founded on bedrock.

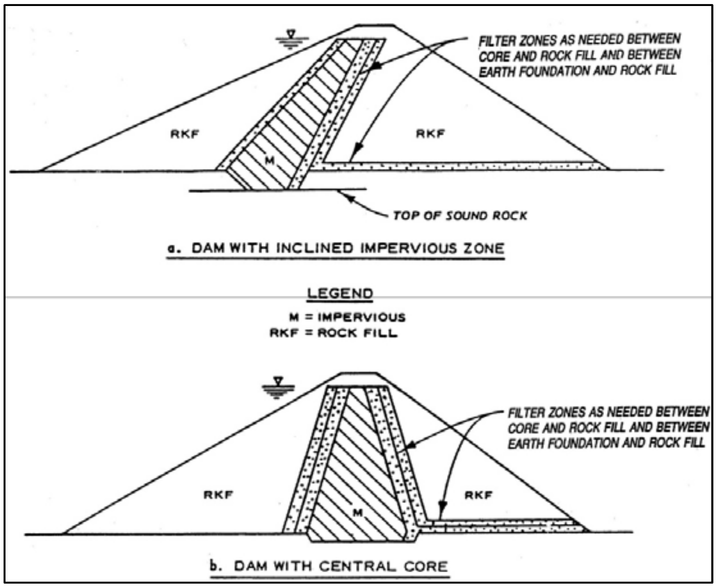

Figure 9. Example of Rock-fill Dam Section Views

The site is located between two reservoirs, so nearby lowland sources of sediment are unavailable without dredging or clamshell excavations. Such excavations are expected to be considered undesirable because of environmental affects and would involve additional cost. In general, dam types that require larger volumes of material are at considerable cost disadvantage compared to lower-volume types because of cost risk associated with the need to import materials.

A rock-fill dam is one composed largely of fragmented rock with an impervious core. The core is separated from the rock shells by a series of transition zones built of properly graded material. A membrane of concrete, asphalt, or steel plate on the upstream face should be considered in lieu of an impervious earth core only when sufficient impervious material is not available (reference 16). This may be the case for the Option 1 site.

Future analyses could confirm rock-fill materials are plentiful, which would be preferred to significantly more expensive concrete. If it is feasible to locate the spillway for Option 1 across the saddle of the ridge on the west side of Deer Creek, a rock-fill dam with an upstream concrete panel membrane could be revisited.

Gravity Dam - Gravity dams are concrete structures that maintain their stability against design loads from the geometric shape and the mass and strength of the concrete. The weight of the material is so great that the hydrostatic load cannot move it. Generally they are constructed in a straight axis, but may be slightly curved or angled to accommodate the specific site conditions. Gravity dams are the most elementary, and therefore, most common dam type (reference 15). See figure 10 for section view.

RCC is the more prevalent construction material for gravity dams as opposed to conventional concrete. RCC is a relatively dry, lean, zero slump concrete material containing coarse and fine aggregate that is consolidated by external vibration using vibratory rollers, dozer, and other heavy equipment. Economic advantages are achieved with rapid placement using construction techniques that are similar to those employed for embankment dams. The material hardens into a true concrete with similar physical properties and appearance to conventional concrete, but at substantially reduced cost. Additionally RCC is environmentally preferable to alternatives as it is less disruptive during construction. Not only is the construction time substantially reduced, but waste water from conventional concrete operations is largely eliminated. Examples of recent RCC dams include Upper Stillwater Dam in Utah (1987), Middle Fork Dam in Colorado (1984), and Galesville Dam in Oregon (1985) (references 17 and 18).

Based on existing available information, further analyses should consider a straight-axis RCC gravity dam or gravity arch dam at the Option 1 site. The site has a length to height ratio less than 4 to 1, making it suitable for an arch dam. However, more information will be required, including abutment geology and a materials survey of the site vicinity, to confirm selection of a particular dam type. Other dam types such as shell dams or rock-fill dams should be considered as additional information is accumulated.

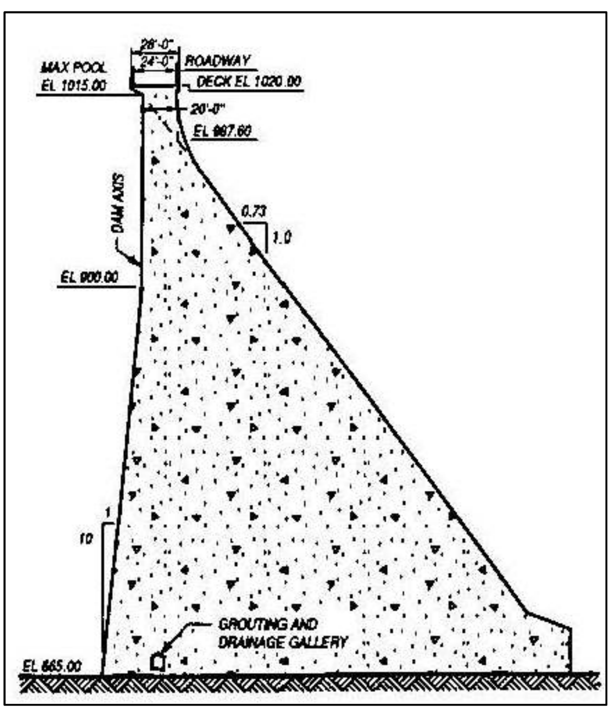

Figure 10. Example of Gravity Dam Section View

Embankment dams typically require about eight times the construction material than corresponding gravity dams, though most of the extra material is rock or earthen fill. Construction material transportation costs would probably be less with arch or gravity dam. A construction material site survey would be needed before completely eliminating the embankment dam option.

5.0 RECOMMENDATIONS AND FUTURE TASKS

Based on existing information and resources available during this analysis, both concepts were found to be technically feasible. Existing information did not identify geologic or engineering constraints that could discount either option in favor of the other. Table 3 summarizes the advantages and disadvantages of both concepts.

If only one concept were pursued, raising Arrowrock Dam is recommended for further study. The existing structure would reduce the quantity of new construction material required, which should provide significant cost advantages. A number of unknowns were identified that add cost risk; however, there are also a number of unknowns associated with building a new dam downstream of Arrowrock Dam. Feasibility study explorations required to obtain information to address the unknowns for either concept are anticipated to be more costly and logistically challenging at a downstream site located in the Lucky Peak reservoir pool than at the existing Arrowrock Dam site.

A risk assessment conducted by a team of Corps and Reclamation engineers and scientists would be informative in further comparing the merits of raising Arrowrock Dam or building a new dam downstream. A rough order of magnitude cost estimate could be calculated to provide additional information about the two concepts. These analyses were outside the current scope of the Lower Boise River Interim Feasibility Study as defined in the agreement between IWRB and the Corps.

Future study of the Arrowrock site would include the tasks described below. This list is not meant to be comprehensive, but identifies major issues that will need to be addressed.

5.1 Construction Materials Survey

A construction materials survey is the recommended next step in evaluating the Arrowrock site. The source of construction materials will largely determine construction costs for a dam raise as well as dam type selection. Dam costs are largely driven by the haul distance of construction materials to the site.

An in-depth survey would be conducted of the surrounding area to determine available construction material type and quantity, including soil, aggregate, and rock. Available materials which may be near or on the dam site include soils for embankments, rock for

Table 3. Comparison of Dam Raise and New Downstream Dam Construction – Advantages and Disadvantages

	ARROWROCK DAM RAISE		NEW DAM - OPTION 1		NEW DAM - OPTION 2	
	Advantages	***Disadvantages***	***Advantages***	***Disadvantages***	***Advantages***	***Disadvantages***
TOPOGRAPHY	Narrow site, protruding ridges, shorter span	Right abutment may not accommodate broader, heavier dam raise structure	Steep competent abutments	Wider river channel, longer axis	Steep competent abutments	Wider river channel, longer axis
GEOLOGY	Granitic bedrock, steeply dipping upstream; similar fracture patterns and spacing	Other minor fracture patterns with less favorable orientations	Granitic bedrock, steeply dipping upstream; similar fracture patterns and spacing	Other minor fracture patterns with less favorable orientations	Granitic bedrock, steeply dipping upstream; potential for more massive rock on right abutment	Other minor fracture patterns with less favorable orientations; longer span to reach competent rock on right abutment
OPERATIONAL IMPACTS	Reduced impact to Lucky Peak reservoir compared to new downstream dam	May have to lower or drain Arrowrock Reservoir for repair and construction efforts on upstream face	Possible reduced impact on Arrowrock reservoir operation	Impinges on Lucky Peak reservoir during exploration and construction	Possible reduced impact on Arrowrock reservoir operation	Impinges on Lucky Peak reservoir during exploration and construction
MATERIALS AND CONSTRUCTION	Significantly less construction material required as existing Arrowrock Dam structure would be incorporated into dam raise	Existing dam concrete is not air-entrained so concrete may be less durable	Greater control over interior design and construction; air entrained concrete and modern construction techniques and standards used	Significantly more material and construction required; Arrowrock Dam abandonment or removal may be cost prohibitive	Greater control over interior design and construction; air entrained concrete and modern construction techniques and standards used	Significantly more material and construction required; Arrowrock Dam abandonment or removal may be cost prohibitive.
EXPLORATION	Can use existing access; could be accomplished in existing dam galleries	Must be coordinated with existing dam operations	Avoids potential conflicts with Arrowrock Dam operations	Exploration would be conducted from barge; extensive excavation for roads and drill pads would be required	Avoids potential conflicts with Arrowrock Dam operations	Exploration would be conducted from barge; extensive excavation for roads and drill pads would be required

embankments and riprap, and concrete aggregate (sand, gravel, and crushed stone). An earth dam may be more economical if suitable soils can be found in nearby borrow pits. The availability of suitable rock may favor a rock-fill dam. A concrete dam may be favored if suitable sand and gravel for concrete is available at a reasonable cost locally or on site (reference 16).

5.2 Geologic Field Investigation

Continued geologic review to determine conditions at Arrowrock Dam is required, progressing to a detailed drilling and sample testing program. The geologic investigation and sampling scope would depend on the geological structure's homogeneity and complexity. The investigation could range from quite limited (where the foundation material is strong even along the weakest potential failure planes) to quite extensive and detailed (where weak zones or seams exist). A minimum level of investigation is required to determine if weak zones are present in the foundation. Field investigations must also evaluate depth and severity of weathering, ground-water conditions (hydrogeology), permeability, strength, deformation characteristics, and ability to excavate. Disturbed and undisturbed samples are required to determine the engineering properties of foundation materials (reference 17) and to evaluate potential materials sources.

5.3 Preliminary Concept Design and Cost Estimates

Additional data collection and analyses should be completed to develop preliminary concept designs and cost estimates. Design concepts should consider any design constraints associated with extending the downstream face into the Lucky Peak reservoir pool and construction constraints associated with the site. The designs must also identify construction sequences and measures that will minimize affects to operation of the current reservoir system.

5.4 Hydrologic and Hydraulic Analyses

Hydrologic and hydraulic analyses are required to determine how a larger facility would be operationally integrated and coordinated with the other Boise River basin storage facilities. This analysis would evaluate the probability of refill to identify the volume of additional stored water that may be available for multiple purposes and the level of additional flood risk reduction that would be provided. The 3055' full pool elevation of Lucky Peak reservoir inundates approximately 35 percent of the Arrowrock Dam face. The Lucky Peak reservoir may have to be substantially drawn down to accommodate construction. Analyses to identify operations to minimize effects to water storage during construction would be required. A new power plant was recently constructed at Arrowrock Dam. Power generation would likely be affected during construction.

5.5 Environmental Surveys and Analyses

Surveys and analyses are required to determine presence and effects to fish, wildlife, plants, and cultural resources. Bull trout are listed as threatened under the Endangered Species Act (ESA) and are known to occur in Arrowrock Reservoir and upstream.

Critical habitat has been designated for bull trout from Arrowrock Reservoir upstream. Consultation under the ESA would be required to identify impacts and determine if a proposed reservoir would jeopardize the existence of this species or affect critical habitat for the species.

Arrowrock Dam is listed on the National Register of Historic Places. According to the State Historic Preservation Office (SHPO), the structure has local and regional significance, and possibly, national significance. Any Federal action that impacts this historic property must evaluate the effects pursuant to the National Historic Preservation Act's guidance and procedures. Avoidance of these effects or mitigation would be required.

6.0 REFERENCES

1. Reclamation, Pacific Northwest Region, *Boise/Payette Water Storage Assessment Report*, 2006.

2. Corps, Walla Walla District, Lower Boise Interim Feasibility Study, *Water Storage Screening Analysis*, August 2010 revised.

3. W. O. Crosby, *Geological Report on the Proposed Main Storage Dam of the Boise, Idaho, Irrigation Project, 25* April 1911.

4. Reclamation, Pacific Northwest Region, Arrowrock Dam, *Geology for Issue Evaluation*, Technical Memorandum No. AO-86-68320-1, September 2009.

5. Engineering News, Vol. 67, No. 23, 6 June 1912.

6. Idaho Geological Survey, *Geological Map of the Idaho City 30x60 Minute Quadrangle*, Thor H. Kiilsgaard, Loudon R. Stanford, and Reed S. Lewis, 2001.

7. Reclamation, Geologic Report, *Arrowrock Dam, Safety of Dams, Modification Decision Analysis*, no date (obtained from Reclamation project files).

8. U. S. Department of Interior, Water and Power Resources Service, *Project Data*, 1981.

9. Reclamation, Pacific Northwest Region, *Summary of Additional Evaluations of Abutment Foundation Blocks at Arrowrock Dam*, Technical Memorandum No. AO-86-68312-3, Appendix A5, August 2009.

10. Reclamation, Technical Service Center, *Arrowrock Reservoir Sediment Quantification and Transport Study Report*, J.A. Bountry and T.J. Randle, 1999.

11. Reclamation, Pacific Northwest Region, Division of Dam Safety, *Seed Report on Arrowrock Dam*, November 1982.

12. Reclamation, Arrowrock Dam, *Selected Photographs from the Media Services (PN-1200) Archives*, December 2003.

13. San Diego County Water Authority, San Vicente Dam Raise, March 2011.

14. Reclamation, http://www.usbr.gov/projects, Theodore Roosevelt Dam, 2009.

15. Historic American Engineering Record, *Arrowrock Dam*, HAER No. ID-27, no date (obtained from Reclamation project files).

16. Corps*, General Design and Construction Considerations for Earth and Rock-Fill Dams*, EM 1110-2-2300, 30 July 2004.

17. Corps, *Gravity Dam Design*, EM 1110-2-2200, 30 June 1995.

18. Historic American Engineering Record, *Twin Springs Irrigation Reservoir and Hydroelectric Project*, FERC Project No. 10669, Consultation Document, October 1990.

19. Corps, Descriptions of Dam Types, *Arch Dam Design*, EM 1110-2-2201, 31 May 1994.

20. Reclamation, *Arrowrock Dam*, Boise River Project, Carl J. Hoffman, Associate Engineer, no date (obtained from Reclamation project files).

21. The Engineers' Club of Dayton, Vol. 3, No. 2, C. H. Paul, November 1916.

Boise GI
Study Area and Vicinity

Figure 11

0 0.5 1 2 Miles

N

US Army Corps of Engineers
Walla Walla District

MAP ID:BoiseGI_20110808
PRJ:\\nww-netapp1.nww.ds.usace.army.mil\nww_egis\Projects\Planning-PPM\BoiseGI\BoiseGI.mxd
DATE:8/8/2011

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Boise GI

Proposed Dam\Reservoir
Existing Condition

Figure 12

0 0.125 0.25 0.5 Miles

N

US Army Corps of Engineers
Walla Walla District

MAP ID:BoiseGI_20110805
PRJ:\\nww-netapp1.nww.ds.usace.army.mil\nww_egis\Projects\Planning-PPM\BoiseGI\BoiseGI.mxd
DATE:8/5/2011

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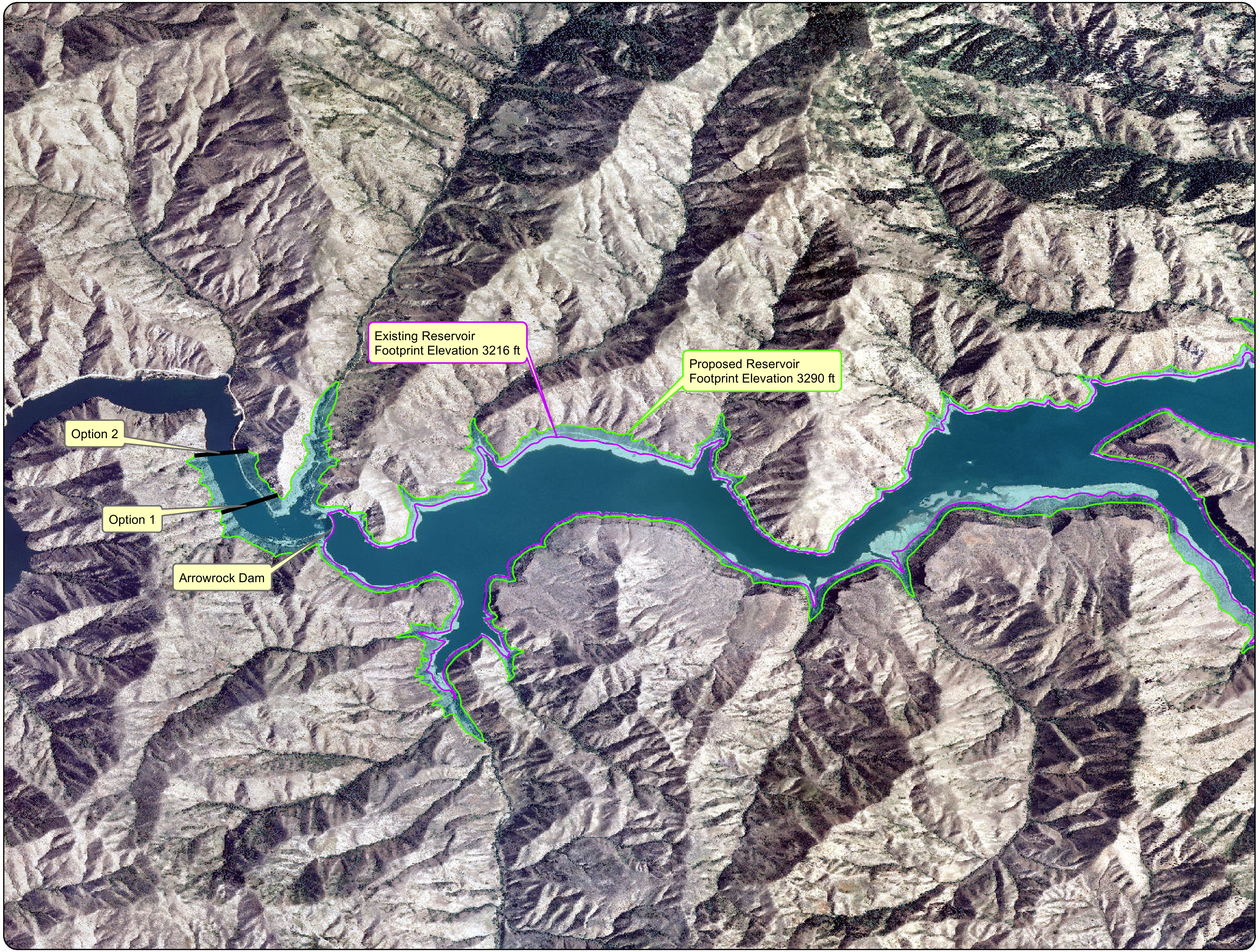
Boise GI

Existing and Proposed Reservoir Footprints



Legend

- Proposed Dams
- Inundate Areas

Figure 13

0 0.125 0.25 0.5 Miles

N

US Army Corps of Engineers
Walla Walla District

MAP ID:BoiseGI_20110808
PRJ:\\nww-netapp1.nww.ds.usace.army.mil\nww_egis\Projects\Planning-PPM\BoiseGI\BoiseGI.mxd
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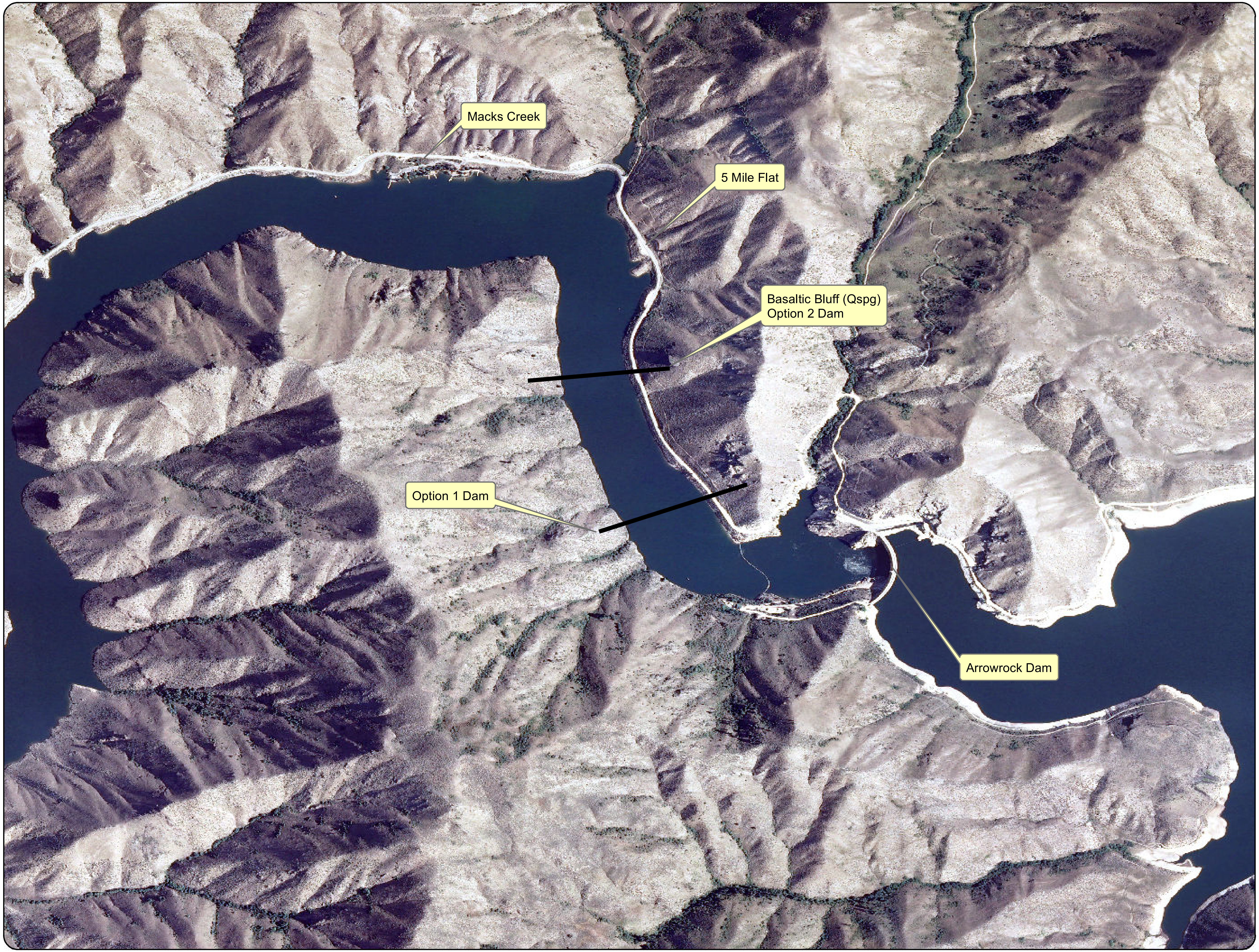
LOOKING TOWARDS NORTH SIDE OF BOISE RIVER

LOOKING TOWARDS SOUTH SIDE OF BOISE RIVER

Figure 14 – Proposed Abutment Locations
Photographs taken 28 July 2011



Boise GI

Proposed Dam Locations

Legend

Proposed Dam

Figure 15

0 0.05 0.1 0.2 Miles

N

US Army Corps of Engineers
Walla Walla District

MAP ID:BoiseGI_20110808
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