Technical Memorandum

CONCEPTUAL DESIGN & COST ESTIMATE

Taiya River Engineered Logjam Bank Protection

Prepared for

Klondike Gold Rush National Historical Park
National Park Service

September 2002

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Geological Resources Division
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September 12, 2002

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Introduction

This technical memorandum summarizes an assessment of the applicability of engineered logjam technology to protect the Dyea town site along the western bank of the Taiya River from continuing erosion. The site is located in Klondike Gold Rush National Historical Park.

Channel migration of the lower Taiya River threatens the historic town site of Dyea, located in southeastern Alaska about 10 miles northwest of Skagway (Figure 1). The Taiya River in the Dyea vicinity has been migrating to the west since the 1960s (Inglis and Pranger 2002). Bank erosion has destroyed approximately 50 percent of the Dyea town site at its northern end. The Klondike Gold Rush National Historical Park would like to protect the cultural resources of Dyea without adversely affecting the natural resources of the Taiya River. The National Park Service (NPS) is investigating engineered logjam technology as a potential strategy to stabilize the eroding river bank and cease the ongoing loss of land at the Dyea town site. Traditional bank protection such as rock revetments can limit erosion when correctly applied but have negative environmental impacts and alters the natural and historic character of the river which the NPS would like to preserve. This technology has the advantage of protecting both cultural and natural resources when properly applied in appropriate settings.

This technical memorandum describes engineered logjam technology, provides a brief geomorphic assessment of the lower Taiya River, determines the feasibility of an engineered logjam bank protection strategy at Dyea, and provides conceptual designs and engineering cost estimates for such a strategy.

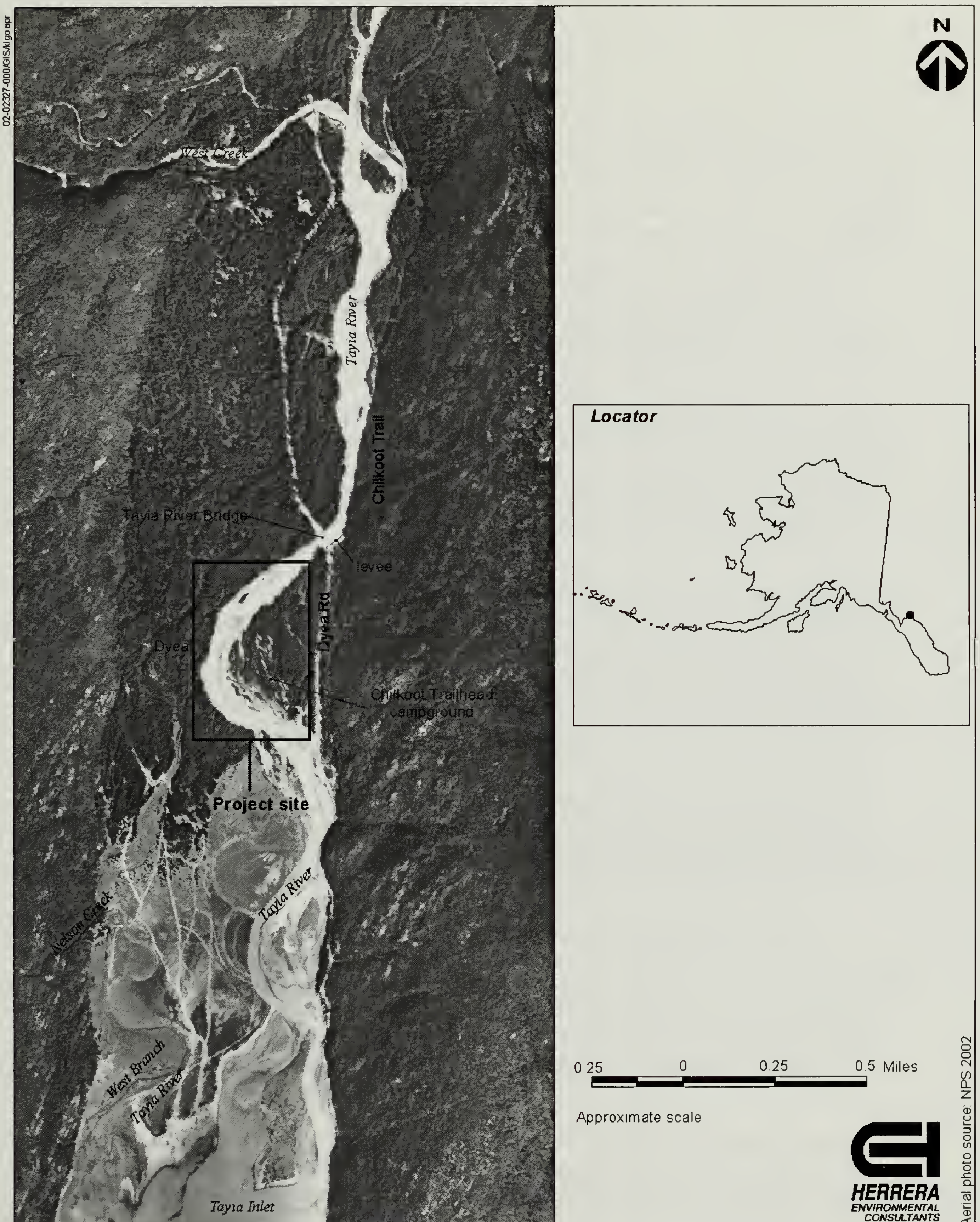

Figure 1. Vicinity map of Tayia River project site at Dyea.

Taiya River and Project Site

The complex and dynamic Taiya River is a free-flowing coastal glacial meltwater river that drains approximately 188 square miles of glaciers and coniferous forests. The lower Taiya River is an anastomosing, low-gradient river with a wide channel migration zone (valley wall to valley wall) characterized by high bed loads and frequent lateral channel migration (Figure 2; Paustian et al. 1994). An anastomosing river consists of multiple channels separated by forested islands that have often developed from bars created by snags and logjams (Figure 3; Abbe and Montgomery 1996; Abbe 2000; Collins and Montgomery 2002; Abbe and Montgomery *in press*). The Taiya River system includes a complex set of geomorphic processes heavily influenced by tectonics, glaciation, mass wasting, vegetation, and wood debris, as summarized by Paustian et al. (1994) and Inglis and Pranger (2002).

The Taiya River watershed has a relatively dry climate unique in southeastern Alaska because the valley is in an orographic rain shadow. Precipitation in the Juneau to Ketchikan area ranges from 90 to 160 inches per year, but Skagway receives only 26 inches per year, on average (NPS 2002). Precipitation also varies significantly throughout the watershed; the Dyea area has an average 39 inches of snowfall annually, whereas the mountain passes average 500 inches (Paustian et al. 1994).

The Taiya River has snow-dominated hydrology, with the highest flows occurring in the summer due to melting snow and glaciers (Figure 4). Winter flows in the Taiya River are minimal because surface water and hyporheic water flows are limited by low temperatures (Paustian et al. 1994). The average summer flow (June – September) is approximately 2,750 cubic feet per second (cfs), and the average winter flow (December – March) is approximately 100 cfs (derived from USGS [2002] gauge records, 1969 to 1977). The highest documented peak flow was approximately 25,000 cfs, which occurred in September 1967.

Most of the Taiya River valley upstream of the West Creek confluence is nearly pristine with little human influence. The Dyea area has been used by humans since the Tlingit used the Chilkoot Trail as a route to the interior (NPS 2002). Limited forest clearing in the Taiya valley occurred in the early twentieth century (Thibault July 2002 personal communication).

The lower Taiya River below the West Creek confluence has been influenced by some development within the channel migration zone. Infrastructure in the Taiya valley includes Dyea Road, the Taiya River bridge (constructed in 1948), the levee just upstream of the bridge on the river's east side (river left), the Chilkoot Trail along the east side of the river, the campground located on the east side of the river, rock revetments along Dyea Road just downstream of the campground, and several residences downstream of the West Creek confluence and on the west side of the Taiya River valley (see Figure 1).

Development in the lower Taiya valley has restricted channel migration. The bridge location and orientation and the levee immediately upstream have confined the river into one channel and orientation, which may have contributed to erosion of the Dyea town site. The levee cuts off a

Figure 2. Taiya River, anastomosing reach upstream of West Creek confluence, looking upstream, July 15, 2002.

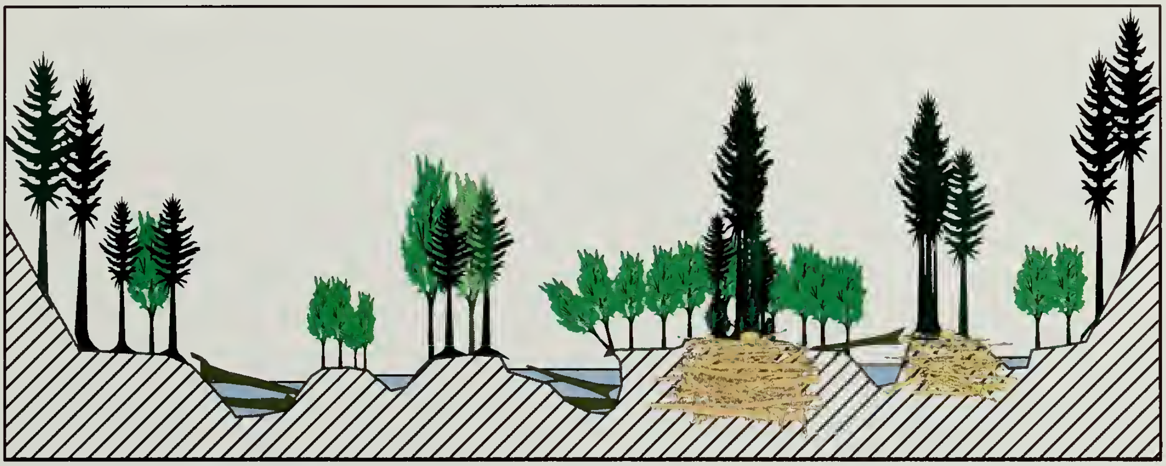

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Figure 3. **Side view of anastomosing river channel.**

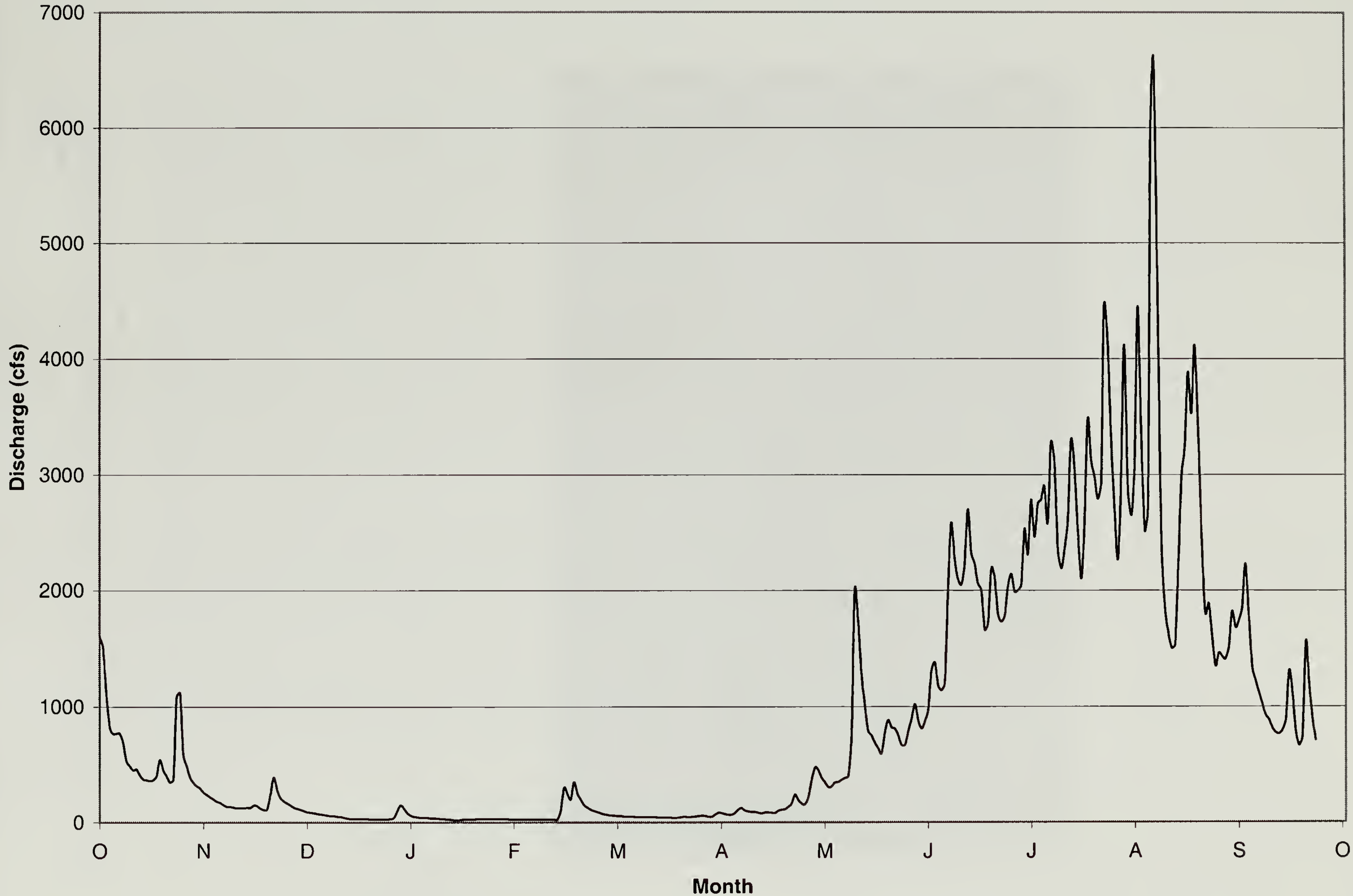

Figure 4. **Annual hydrograph of Tayia River (10/1/72 - 9/30/73; USGS gage # 15056210)**

Figure 5. Taiya River near Dyea at flood stage, July 23, 2002 looking upstream. Campground on right is partially inundated. Flow direction is from top to bottom.

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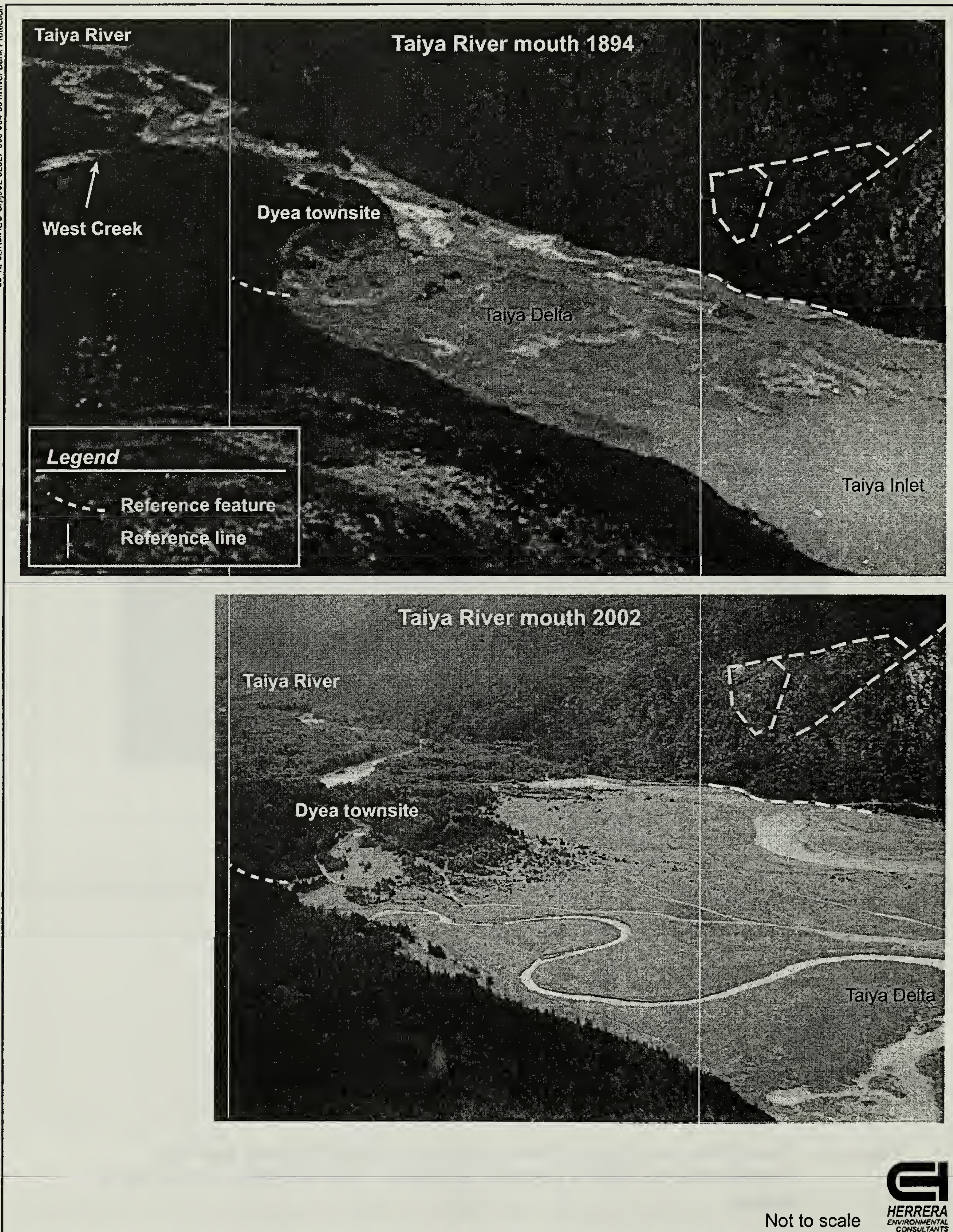

Figure 6. Historical photo of Taiya River delta, 1894, looking northeast (top photograph). Lower photograph illustrates similar perspective in 2002.

Engineered Logjams

The term *engineered logjam* (ELJ) refers to an instream structure designed (i.e., engineered) to emulate natural logjams and fluvial processes in order to achieve physical and ecological objectives. Engineered logjams consist of a designed framework of interlocking native wood debris and alluvium. The technology is based on the premise that manipulating fluvial environments, whether for traditional river engineering problems (e.g., flood control, bank protection) or for habitat restoration, is more likely to be sustainable if it is done in a way that emulates natural landscape processes. The concept of engineered logjams began with the observation that natural logjams formed "hard points" providing long-term forest refugia (Abbe and Montgomery 1996). Such natural hard points create stable foundations for forest growth within a dynamic alluvial environment subject to frequent disturbance.

If properly designed and placed, these structures can cause predictable stream or river system reactions that enhance stream bank protection and aquatic habitat. Their primary benefit is in reintroducing physical complexity to rivers, providing cover, pools, and riparian habitat (Figure 7). Experience to date suggests that engineered logjams can provide a viable method for bank protection and for managing debris (especially mobile wood) that may be hazardous to bridges and culverts (Abbe and Montgomery *in press*). At the same time, installation of an engineered logjam can reestablish important habitat elements of forest streams degraded by conventional river engineering.

In addition to delivering ecological benefits and controlling erosion, engineered logjams can be economically competitive with more traditional engineering practices (Abbe et al. 1997). For example, a costly bank stabilization project along North Chickamauga Creek in southeastern Tennessee was proposed, but abandoned, by the US Army Corps of Engineers (USACE). The proposed plan would have consisted of a 130-foot-wide by 2,600-foot-long channel with rip-rap protection along the toe of the eroding bank. This project was estimated to cost $3M and was abandoned because USACE determined that project costs were greater than project benefits (USACE, 2002). Traditional river engineering techniques may have additional costs beyond design and construction costs, such as mitigation costs and maintenance costs. Engineered logjam projects do not incur these costs because they improve aquatic habitat and are self-mitigating.

Natural jam types recognized from field observations in an old-growth temperate rain forest in western Washington (i.e., flow-deflection jams, bar apex jams, and meander jams) provide models for the design of bank protection engineered logjams in a wide variety of sites and under different constraints (Abbe and Montgomery *in press*). The recommended design strategy begins with an understanding of the river (e.g., channel dynamics, hydrology, hydraulics, riparian forest conditions, and wood debris characteristics) and then identification of the appropriate natural logjam analog. The engineered logjam design is developed to meet project conditions, objectives, and constraints.

Figure 7. North Fork Stillaguamish flow deflection engineered logjam, post-construction.

Although several engineered logjam projects constructed since 1995 in western Washington have performed well through large magnitude floods, the technology remains experimental and should be applied only by those with expertise in forest river geomorphology, wood debris mechanics, hydraulic engineering, and river corridor management. The projects constructed to date confirm that post-construction inspections and maintenance should be an essential part of engineered logjam projects intended to protect property or infrastructure. While the demonstration projects show the technology to be an environmentally and economically viable alternative to traditional river engineering in certain applications, inappropriate design and application of engineered logjams can have adverse impacts such as accelerated bank erosion, unstable debris, channel avulsions, increased flood inundation, and impediments to navigation.

Like natural logjams, engineered logjams introduce complexity to a river that can pose hazards to recreational boaters unfamiliar with forest rivers. With proper design and installation, engineered logjams pose less of a hazard than natural logjams with which experienced boaters on the Taiya are familiar. Engineered logjams constructed in western Washington have been popular with fishermen and may therefore be considered “attractive nuisances.” Application of engineered logjam structures should include appropriate signage and public education.

Although wood structures such as crib walls, weirs, pile dikes, and deflectors have been used in stream channels for centuries, woody debris is rarely used in current river engineering (with the exception of habitat enhancement projects). Natural wood debris accumulations in large alluvial channels can be extremely stable and effective at river training beyond the 50-year design life of most river engineering projects (Abbe et al. 1997; Abbe et al. *in press*). The stability of natural wood debris jams can be enhanced and quantified using geomorphic and engineering principles in hydraulics, statics, and geomechanics to guide the design of engineered logjams. Many of the ecological characteristics river professionals are increasingly asked to preserve or restore (Shields et al. 1995) are integral to engineered logjams because they emulate the most biologically productive, natural structures in a river. Because of the net ecological benefits delivered by engineered logjams, they offer a self-mitigating form of bank protection.

Physical and biological monitoring of engineered logjam projects in western Washington has demonstrated that the structures offer a viable alternative for bank protection that enhances salmonid habitat (Abbe and Montgomery *in press*). Constructed logjams in the lower Elwha River were subjected to a 50-year flood event in the winter of 2001–2002 and performed as intended. Biological monitoring of engineered logjam projects in the lower Elwha and North Fork Stillaguamish rivers is showing that the structures are heavily utilized by juvenile and adult salmon (Pess et al. *in preparation*).

To date, successful implementation of engineered logjam structures has included more than 32 structures in six rivers in Washington state and 15 structures in a gravel-bedded river in New South Wales, Australia (Abbe et al. *in press*, Abbe et al. *in review*). Similar structures have also been successfully implemented in sand-bedded rivers in the southeastern United States (Shields 2002).

A 1999 roadway protection project for a site on the Cispus River in the Gifford Pinchot National Forest in Washington state provides a good example of a project that had goals similar to those of the Klondike Gold Rush National Historical Park for the Dyea town site (Abbe and Montgomery *in press*). The impetus for the Cispus River project was an estimated 500-year flood event in February 1996 that caused a tremendous amount of damage in the Cispus watershed. Overall damage along the Cispus River involved the loss of personal property, erosion and loss of stream banks, bridge failures, and road segment washouts. An engineered logjam project was designed and implemented in 1999 to protect two road sites and an archaeological site adjacent to the Cispus River. Design objectives were to use unanchored wood to deflect flow and to create a riparian buffer, beneficial fish habitat, and aesthetically pleasing structures (Figure 8).

Design for the three Cispus River engineered logjam projects and construction of two of the sites (a total of seven engineered logjams and a 150-foot log crib) to protect about 500 feet of bank amounted to total costs of approximately $300,000. Plan and cross-section views are included for a typical deflector jam used in these projects (Figure 9). The basic construction sequence is illustrated in Figure 10.

By the spring of 2000, winter high flows in the Cispus River had created pools at each of the structures, and fish were using the project site. The sites have experienced several overtopping flows, and no change in jam configuration or integrity has been observed since construction. The engineered structures have achieved the project goals to protect the road and create beneficial habitat. After the first post-construction winter, over 150 salmon redds were documented at one site where there had been none previously. Fish use near the engineered structures was also observed to be tenfold that of other areas of the river.

Before
Traditional rock blanket revetment, Cispus River, 1999

After
Engineered Logjam bank protection, Cispus River, 1999

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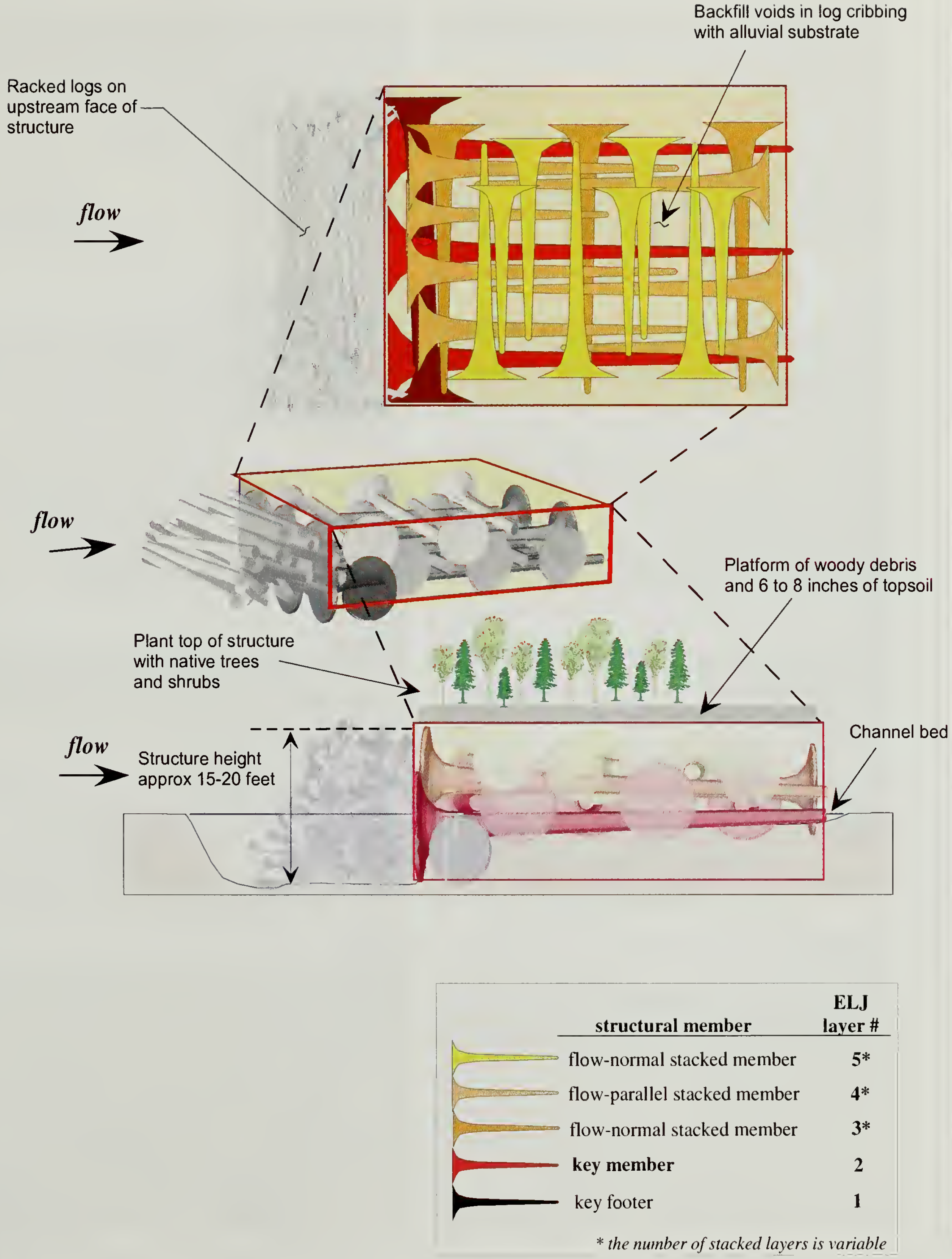
Figure 8. Before and after photographs of Cispus River engineered logjam project.



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Not to scale

Figure 9. Conceptual details of Cispus River engineered logjam structure.

1999 Cispus River engineered logjam project, Site B.
Cowlitz Valley Ranger District, Gifford Pinchot National Forest, Washington.

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Figure 10. Construction sequence for Cispus River engineered logjam project.

Conceptual Designs

Logjams are a common and critical element of the lower Taiya River, according to the historical analysis, field observations in July 2002, and observations by others (Inglis and Pranger 2002; Watson 2002 personal communication; Paustian et al. 1994). An engineered logjam bank protection strategy is feasible for the Dyea town site and is consistent with the geomorphic setting and processes in the lower Taiya River.

Two basic conceptual design strategies that incorporate engineered logjam structures are presented here. Both options incorporate a series of flow deflector structures along the west (river right) bank that would function as a unit to provide local, long-term bank protection for the Dyea town site. Size and spacing of these structures are based largely on experimental studies of flow deflection by rock groins and pile dikes (Klingeman 1984), along with results from engineered logjam applications to date (Abbe et al. *in press*). Flow deflector jams deflect high-velocity flow away from the eroding bank and create a more complicated but stable shoreline. These structures tend to be significantly rougher than conventional rock groins and revetments, reducing shear stresses along the bank. In addition, these structures can be built with minimal disturbance to the adjacent bank. Bank regrading is not necessary, unlike a rip-rap bank protection strategy that would require regrading and further loss of the historic site of Dyea.

In this technical memorandum, dimensions and numbers of engineered logjam structures are conceptual only, and should not be used for construction. Further design analysis is necessary to finalize design plans and specifications.

The first option (option A, shown in Figure 11) involves treating only the eroding west (right) bank along the Dyea town site and requires no change to the current management of the campground on the left bank floodplain opposite the site. Option A consists of a series of approximately 10 flow deflector logjams along the right bank spaced approximately 220 feet apart. The flow deflector logjams in option A would be approximately 40 feet wide, 90 feet long, and 15 to 20 feet high (extending 5 to 10 feet into the channel bed). Because these structures would only occupy 10 percent of the channel's width, they are not expected to adversely affect the existing campground area. Option A would not put any additional flooding pressure or channel avulsion risk on the campground beyond the current flooding problems and risks that are inherent to any active floodplain. Alluvium excavated from the engineered logjam footprints will be placed between the engineered logjams along the vertical banks to create a bioengineered and vegetated embankment. The average height of the embankment will be 10 feet with average side slopes at 3H:1V.

The second option (option B, shown in Figure 12) involves treating the entire active Taiya River corridor between Dyea Road and the Dyea town site. Option B is a more comprehensive plan that protects the Dyea town site and rehabilitates habitat in the lower Taiya River by restoring a more natural anastomosing character to the project reach, but it requires abandoning the campground. The flow deflector logjams in option B along the west (right) bank would be larger than in option A, approximately 75 feet wide, 90 feet long, and 15 to 20 feet high. Because of their size, fewer structures (five or six) are needed to protect the 2,200 feet of bank length. Alluvium excavated from the engineered logjam footprints will be placed between the engineered logjams along the vertical banks to create a bioengineered and vegetated embankment. The average height of the embankment will be 10 feet with average side slopes at 3H:1V. By occupying approximately one fifth of the active channel, these structures would exert more pressure on the left bank in the form of increased flooding and possible formation of secondary channels. Option B would achieve bank protection for the Dyea town site and would restore the project reach to a functioning, anastomosing system.

Another recommended element for option B involves adding a bar apex logjam approximately 1,100 feet downstream of the Taiya River bridge along the east (left) bank. A bar apex logjam in this location would actively divert high flows into the left bank floodplain and promote the formation of a secondary channel, alleviating pressure along the Dyea town site. The dimensions of this bar apex logjam would be approximately 90 feet in length, 50 feet in width, and 15 to 20 feet in height. Figure 13 illustrates a natural bar apex logjam in plan and cross-section views.

The next steps for proceeding with option A or option B are to develop final design plans and specifications, to acquire all necessary permits, and to complete any required environmental review. Construction of a project of this magnitude requires approximately 4 to 8 weeks. General specifications for logs and materials required for construction are provided in Appendix A. The general sequence for the construction of either option A or option B is as follows:

1. Install cofferdam or other dewatering facilities, including settling pond as needed.

2. Excavate the footprint for the engineered logjam foundation and racked member trench.

3. Place key, stacked, and inclined pile log members forming the logjam foundation.

4. Place alluvium backfill for ballast within the cribbing.

5. Place racked log members upstream of the logjam foundation.

6. Place woody material on the top of the cribbing to create a platform for soil and plantings above the logjam foundation (not above racked members).

7. Place 6 to 8 inches of topsoil on the platform.

8. Regrade disturbed alluvium surrounding the structure.

08-29-02/rtb/HEC-O/pj/02-02327-000-004-001/River Bank Protection

Figure 11. **Conceptual plan view of flow deflector engineered logjams for option A.**

Figure 12. Conceptual plan view of flow deflector and bar apex engineered logjams for option B.

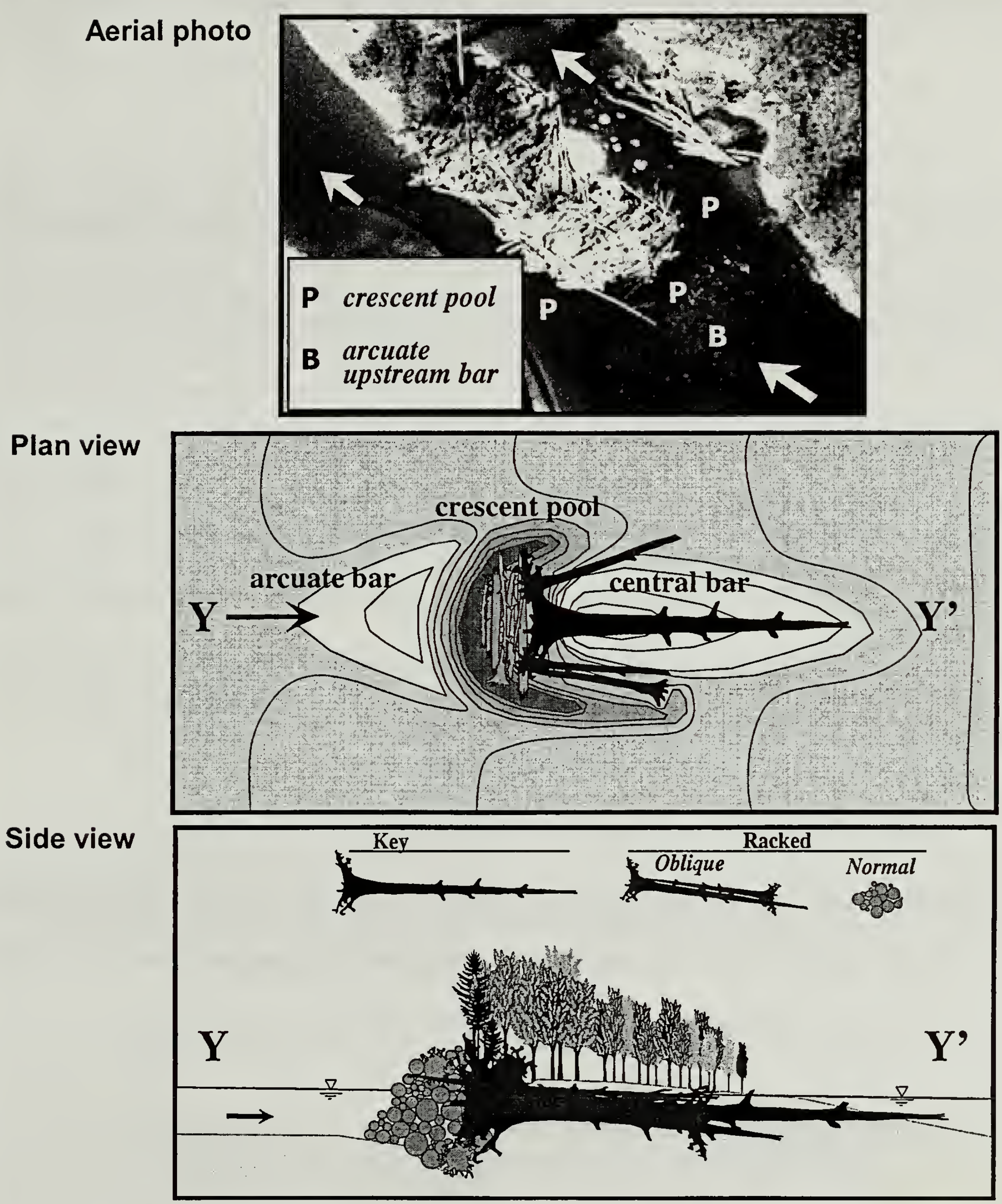

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Figure 13. Natural bar apex logjam in photo, plan view, and side view.

9. Remove the cofferdam.

10. Plant native tree and shrub species in the topsoil, and provide erosion control measures as necessary to prevent soil erosion during the plant establishment period.

Cost Estimates

A cost estimate for engineering fees such as final design plans, specifications, and permit assistance is provided as a line item in Tables 1 and 2. Preliminary construction cost estimates are provided in Tables 1 and 2 for construction of options A and B, respectively. More detailed construction cost estimates will be developed during design.

An estimate of the consulting engineering budget for final designs and specifications, permit assistance, and construction oversight totals $210,955. This estimate includes $98,091 for regulatory permitting. Construction costs for implementing options A or B could range from $3,945,939 to $3,298,350, respectively (Tables 1 and 2). These construction cost estimates represent a rough approximation of the total funds needed to complete the engineered logjam project as described above and include a 20% contingency. These cost estimates will be revised and finalized after a site visit by an engineer to review construction conditions and solidify material sources. Final design and permitting costs in Table 1 are assumed to be similar for both conceptual design options.

The largest single cost component, logs, is also the most uncertain. Estimated log costs for options A and B, are $2,080,000 and $1,491,000, respectively, or approximately 60% of the total estimated project costs. These log costs do not include barging and assume that the logs are purchased from a third-party source, most likely Sealaska Corporation. Other sources, possibly internal, could serve to realize significant cost savings and should be explored.

Cost estimate assumptions for final design and specifications include:

- Preparation of technical specifications to be included as special provisions to the Parks Department contracting format.
- Preparation of 60 percent and 90 percent complete contract drawings and specifications for client review.
- Preparation of final drawings and a copy master of the final technical specifications for inclusion into bid package.
- Preparation of specifications in Construction Specifications Institute (CSI) format.
- Parks Department to provide consultant with boiler-plate general contract requirements (Division 1 specifications in CSI format) for editing.
- Parks Department to assemble bid package and prepare contract requirements (Division 0 specifications in CSI format).

Cost estimate assumptions for environmental review and permitting include:

- One round trip for two people (fluvial geomorphologist and land use planner) would be required for the pre-application conference and environmental assessment initiation. A site visit would be included in this trip.

- The National Park Service would provide all necessary information on historic and cultural resources for compliance with the National Environmental Policy Act (NEPA) and section 106 of the National Historic Preservation Act.

- A draft scope for the environmental assessment would be prepared for the initial public notice. The National Park Service would complete the scope and publish the notice according to National Park Service polices.

- The environmental assessment (approximately 50 pages) would be prepared.

- Up to 10 copies of the draft environmental assessment would be produced for review by the National Park Service. After incorporation of agency comments, a final camera-ready copy would be produced for agency approval. Up to 40 copies of the environmental assessment would be provided.

The main assumptions for the Engineer's Cost Estimate include the following:

- Unit costs were obtained from the *RSMeans – Heavy Construction Cost Data 2002, 16th Annual Edition* (RSMeans) and from local vendor quotes

- A City Cost Index (CCI) multiplier of 1.35 was used to adjust the RSMeans unit costs for Division 02 Site Construction line items (as referenced in Tables 1 and 2). The CCI applies to Juneau and Anchorage. This is close to the 1.293 location factor multiplier also referenced in RSMeans for the Ketchikan Area.

- Local vendor quotes are approximate and are based on the preliminary design parameters provided to the vendors. These quotes will need to be updated and changed as final design progresses.

- The quantities in Tables 1 and 2 are approximate and are based on the preliminary design parameters. The quantities should be re-evaluated during final design so that the construction cost estimate can be updated.

- Costs for the supply of the log materials are based on conversations with Mr. Bob Girt of Sealaska Corporation. It is important to note that the supply of logs with intact rootwads is an entirely new concept to the

Table 1. ılong bank).

ITEM		DESCRI	
1		Mobilization/Demobilizatio	
2		Special Transportation (Log	
3		Temporary Construction Ac	
	a	Entrance	
	b	Clearing	
	c	Grading	
	d	Road Construction	·pending on soils and alignment
	e	Geotextile/Geogrid	
4		TESC - Silt Fence	
5		Diversion Dyke (for norther	
6		Bypass Channel Constructic	
	a	Clearing	
	b	Channel Excavation	stockpile)
	c	Main Channel temporary	
	d	Settling basin	
	e	Temporary Bridge constr	
	f	Bypass Restoration (fill i	
7		Channel Bank Construction	
	a	Clearing	
	b	Embankment Placement/	ustment
	c	Final Grading	
8		Water Control/Pumping	
9		Lighting system	
10		ELJ Structure Construction	
	a	Excavation	
	b	Footer and Key Logs	
	c	Stacked logs	
	d	Racked logs w/o root wa(	
	e	Racked logs w/ root wad	
	f	Piling logs	
	g	Embankment/compaction	ustment
11		Log Materials (excluding ba	
	a	Footer/Key/Stacked - 30"	
	b	Stacked/Racked - 12" to :	
	c	Stacked/Racked - 12" to :	
	e	Piling logs	
12		Aggregate Materials & Place	
	a	Embankment	
	b	Topsoil Import	
13		Planting - Sitka Spruce - 2 G	
14		Planting - Alders - 2 Gallon	
15		Planting - Western Red Ceda	

Table 1. Engineer's cost estimate for Taiya River engineered logjam project, option A (small engineered logjams along bank).

ITEM		DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL COST	REFERENCE
1		Mobilization/Demobilization (10% of subtotal)	LS	1	$289,291.75	$289,292	
2		Special Transportation (Log Barging)	LS	1	$315,000.00	$315,000	Boyer Marine Barge - $7,500 per day
3		Temporary Construction Access Road					
	a	Entrance	EA	1	$10,000.00	$10,000	Quarry spall - 100 feet x 30 feet x 12" thick
	b	Clearing	Acre	0.9	$7,560.00	$6,804	RS Means - Heavy Construction - 02230-200-0350
	c	Grading	SY	2,700	$0.45	$1,203	RS Means - Heavy Construction - 02310-440-0200
	d	Road Construction	SY	2,700	$13.03	$35,174	RS Means - Heavy Construction - 01550-700-0100 (8" deep)- Optional depending on soils and alignment
	e	Geotextile/Geogrid	SF	3,000	$1.32	$3,960	Guide - Div 2 - 2-35 - (Mirafi #140N)
4		TESC - Silt Fence	LF	4,500	$1.26	$5,650	RS Means - Heavy Construction - 02370-550-1100
5		Diversion Dyke (for northern ELJs)	CY	500	$1.19	$594	RS Means - Heavy Construction - 02315-410-5000
6		Bypass Channel Construction					
	a	Clearing	Acre	0.35	$265.95	$93	RS Means - Heavy Construction - 02230-220-0550
	b	Channel Excavation	CY	5,700	$1.19	$6,772	RS Means - Heavy Construction - 02315-410-5000 (includes 50' haul for stockpile)
	c	Main Channel temporary levy	CY	500	$1.19	$594	RS Means - Heavy Construction - 02315-410-5000
	d	Settling basin	CY	1,500	$1.19	$1,782	RS Means - Heavy Construction - 02315-410-5000
	e	Temporary Bridge construction	EA	1	$7,000.00	$7,000	
	f	Bypass Restoration (fill in when complete)	CY	7,200	$0.72	$5,152	RS Means - Heavy Construction - 02315-120-5000
7		Channel Bank Construction					
	a	Clearing	Acre	0.5	$265.95	$133	RS Means - Heavy Construction - 02230-220-0550
	b	Embankment Placement/compaction	CY	16,850	$6.80	$114,647	Means, FE Loader, 300' Haul, Sand and Gravel, compacted, w/Alaska adjustment
	c	Final Grading	SY	12,533	$0.22	$2,707	RS Means - Heavy Construction - 02310-440-3310
8		Water Control/Pumping	Days	30	$194.40	$5,832	RS Means - Heavy Construction - 02240-500-0600
9		Lighting system	Days	30	$216.54	$6,496	RS Means - Heavy Construction - 01590-400-1960 (2-systems)
10		ELJ Structure Construction	EA	10	$13,671.12	$136,711	
	a	Excavation	CY	1,333	$3,000.00		Means, experience, Alaska factor
	b	Footer and Key Logs	EA	5	$250.00		Means, experience, Alaska factor
	c	Stacked logs	EA	38	$570.00		Means, experience, Alaska factor
	d	Racked logs w/o root wad	EA	90	$900.00		Means, experience, Alaska factor
	e	Racked logs w/ root wad	EA	10	$200.00		Means, experience, Alaska factor
	f	Piling logs	EA	5	$50.00		Means, experience, Alaska factor
	g	Embankment/compaction	CY	1,279	$8,701.12		Means, FE Loader, 300' Haul, Sand and Gravel, compacted, w/Alaska adjustment
11		Log Materials (excluding barging)					
	a	Footer/Key/Stacked - 30" to 48" with root wad	EA	430	$3,500.00	$1,505,000	Supply from Sealaska Corporation
	b	Stacked/Racked - 12" to 24" with root wad	EA	100	$1,000.00	$100,000	Supply from Sealaska Corporation
	c	Stacked/Racked - 12" to 24" without root wad	EA	900	$500.00	$450,000	Supply from Sealaska Corporation
	e	Piling logs	EA	50	$500.00	$25,000	Supply from Sealaska Corporation
12		Aggregate Materials & Placement					
	a	Embankment	CY	29,638	$0.00	$0	Means, FE Loader, 300' Haul, Sand and Gravel, w/Alaska adjustment
	b	Topsoil Import	CY	2,089	$20.66	$43,146	Means Topsoil material only, plus Alaska adjustment
13		Planting - Sitka Spruce - 2 Gallon	EA	564	$58.00	$32,712	Vendor Quote (seed 'n' tree) plus $15/plant installation
14		Planting - Alders - 2 Gallon	EA	282	$19.50	$5,499	Vendor Quote (seed 'n' tree) plus $10/plant installation
15		Planting - Western Red Cedar - 2 Gallon	EA	282	$51.25	$14,453	Vendor Quote (seed 'n' tree) plus $15/plant installation

Table 1. I llong bank).

ITEM	DESCRIP
16	Planting - Shrub - Oregon G
17	Planting - Shrub - red huckle
18	Planting - bearberry - 1 Gall
19	Planting - yarrow - 1 Gallon
20	Planting - mahonia repends -
21	Vegetative Plantings - Live S
22	Planting delivery - barge
	SUBTOTAL
	20% Contingency
	Sales Tax (4% - Skagway)
	CONSTRUCTION SUBTC
	Engineering Fees
	Permit Assistance Fees
	TOTAL

Table 1. Engineer's cost estimate for Taiya River engineered logjam project, option A (small engineered logjams along bank).

ITEM	DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL COST	REFERENCE
16	Planting - Shrub - Oregon Grape - 1 Gallon	EA	865	$8.35	$7,223	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
17	Planting - Shrub - red huckleberry - 1 Gallon	EA	865	$8.65	$7,482	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
18	Planting - bearberry - 1 Gallon	EA	940	$6.75	$6,345	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
19	Planting - yarrow - 1 Gallon	EA	1,034	$7.35	$7,600	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
20	Planting - mahonia repends - 1 Gallon	EA	808	$6.75	$5,454	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
21	Vegetative Plantings - Live Stakes	EA	1,300	$2.00	$2,600	Vendor Quote (seed 'n' tree) plus $1.00/plant installation
22	Planting delivery - barge	EA	1	$14,100.00	$14,100	Vendor Quote
	SUBTOTAL				**$3,182,209**	
	20% Contingency				**$636,442**	
	Sales Tax (4% - Skagway)				**$127,288**	
	CONSTRUCTION SUBTOTAL				**$3,945,939**	
	Engineering Fees				**$109,465**	
	Permit Assistance Fees				**$101,490**	
	TOTAL				**$4,156,894**	

Table 2. Engi;ineered logjams).

ITEM		DESCRIPTIOI	
1		Mobilization/Demobilization (10	
2		Special Transportation (Log Barg	
3		Temporary Construction Access I	
	a	Entrance	
	b	Clearing	
	c	Grading	
	d	Road Construction	ding on soils and alignment
	e	Geotextile/Geogrid	
4		TESC - Silt Fence	
5		Diversion Dyke (for northern ELJ	
6		Bypass Channel Construction	
	a	Clearing	
	b	Channel Excavation	:r)
	c	Main Channel temporary levy	
	d	Settling basin	
	e	Temporary Bridge constructioi	
7		Channel Bank Construction	
	a	Clearing	
	b	Embankment Placement	nent
	c	Final Grading	
8		Water Control/Pumping	
9		Lighting system	
10		ELJ Structure Construction	
	a	Excavation	
	b	Footer and Key Logs	
	c	Stacked logs	
	d	Racked logs w/o root wad	
	e	Racked logs w/ root wad	
	f	Piling logs	
	g	Embankment/compaction	nent
11		Apex ELJ Structure Construction	
	a	Excavation	
	b	Footer and Key Logs	
	c	Stacked logs	
	d	Racked logs w/o root wad	
	e	Racked logs w/ root wad	
	f	Piling logs	
	g	Embankment/compaction	nent
12		Log Materials (excluding barging)	
	a	Footer/Key/Stacked - 30" to 48	
	b	Stacked/Racked - 12" to 24" w	
	c	Stacked/Racked - 12" to 24" w	

Table 2. Engineer's cost estimate for Taiya River engineered logjam project, option B (remove campground - large engineered logjams).

ITEM		DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL COST	REFERENCE
1		Mobilization/Demobilization (10% of subtotal)	LS	1	$241,814.51	$241,815	
2		Special Transportation (Log Barging)	LS	1	$262,500.00	$262,500	Boyer Marine Barge
3		Temporary Construction Access Road					
	a	Entrance	EA	1	$10,000.00	$10,000	Quarry spall - 100 feet x 30 feet x 12" thick
	b	Clearing	Acre	0.9	$7,560.00	$6,804	RS Means - Heavy Construction - 02230-200-0350
	c	Grading	SY	2,700	$0.45	$1,203	RS Means - Heavy Construction - 02310-440-0200
	d	Road Construction	SY	2,700	$13.03	$35,174	RS Means - Heavy Construction - 01550-700-0100 (8" deep)- Optional depending on soils and alignment
	e	Geotextile/Geogrid	SF	3,000	$1.32	$3,960	Guide - Div 2 - 2-35 - (Mirafi #140N)
4		TESC - Silt Fence	LF	4,500	$1.26	$5,650	RS Means - Heavy Construction - 02370-550-1100
5		Diversion Dyke (for northern ELJs)	CY	500	$1.19	$594	RS Means - Heavy Construction - 02315-410-5000
6		Bypass Channel Construction					
	a	Clearing	Acre	0.35	$265.95	$93	RS Means - Heavy Construction - 02230-220-0550
	b	Channel Excavation	CY	5,700	$3.11	$17,706	RS Means - Heavy Construction - 02315-410-5400 (includes 300' haul to river)
	c	Main Channel temporary levy	CY	500	$1.19	$594	RS Means - Heavy Construction - 02315-410-5000
	d	Settling basin	CY	1,500	$1.19	$1,782	RS Means - Heavy Construction - 02315-410-5000
	e	Temporary Bridge construction	EA	1	$7,000.00	$7,000	
7		Channel Bank Construction					
	a	Clearing	Acre	0.5	$265.95	$133	RS Means - Heavy Construction - 02230-220-0550
	b	Embankment Placement	CY	32704	$6.80	$222,518	Means, FE Loader, 300' Haul, Sand and Gravel, compacted, w/Alaska adjustment
	c	Final Grading	SY	15839	$0.22	$3,421	RS Means - Heavy Construction - 02310-440-3310
8		Water Control/Pumping	Days	30	$194.40	$5,832	RS Means - Heavy Construction - 02240-500-0600
9		Lighting system	Days	30	$216.54	$6,496	RS Means - Heavy Construction - 01590-400-1960 (2-systems)
10		ELJ Structure Construction	EA	6	$22,072.98	$132,438	
	a	Excavation	CY	1,333	$3,000.00		Means, experience, Alaska factor
	b	Footer and Key Logs	EA	8	$440.00		Means, experience, Alaska factor
	c	Stacked logs	EA	32	$544.00		Means, experience, Alaska factor
	d	Racked logs w/o root wad	EA	100	$1,000.00		Means, experience, Alaska factor
	e	Racked logs w/ root wad	EA	10	$200.00		Means, experience, Alaska factor
	f	Piling logs	EA	7	$70.00		Means, experience, Alaska factor
	g	Embankment/compaction	CY	2,472	$16,818.98		Means, FE Loader, 300' Haul, Sand and Gravel, compacted, w/Alaska adjustment
11		Apex ELJ Structure Construction	EA	1	$22,009.98	$22,010	
	a	Excavation	CY	1,333	$3,000.00		Means, experience, Alaska factor
	b	Footer and Key Logs	EA	5	$275.00		Means, experience, Alaska factor
	c	Stacked logs	EA	38	$646.00		Means, experience, Alaska factor
	d	Racked logs w/o root wad	EA	100	$1,000.00		Means, experience, Alaska factor
	e	Racked logs w/ root wad	EA	10	$200.00		Means, experience, Alaska factor
	f	Piling logs	EA	7	$70.00		Means, experience, Alaska factor
	g	Embankment/compaction	CY	2,472	$16,818.98		Means, FE Loader, 300' Haul, Sand and Gravel, compacted, w/Alaska adjustment
12		Log Materials (excluding barging)					
	a	Footer/Key/Stacked - 30" to 48" with root wad	EA	245	$3,900.00	$955,500	Supply from Sealaska Corporation
	b	Stacked/Racked - 12" to 24" with root wad	EA	70	$1,300.00	$91,000	Supply from Sealaska Corporation
	c	Stacked/Racked - 12" to 24" without root wad	EA	700	$600.00	$420,000	Supply from Sealaska Corporation

Table 2. Engiïgineered logjams).

ITEM		DESCRIPTIOI
	e	Piling logs
13		Aggregate Materials & Placement
	a	Embankment
	c	Topsoil Import
14		Planting - Sitka Spruce - 2 Gallon
15		Planting - Alders - 2 Gallon
16		Planting - Western Red Cedar - 2
17		Planting - Shrub - Oregon Grape -
18		Planting - Shrub - red huckleberry
19		Planting - bearberry - 1 Gallon
20		Planting - yarrow - 1 Gallon
21		Planting - mahonia repends - 1 Ga
22		Vegetative Plantings - Live Stake:
23		Planting delivery - barge
		SUBTOTAL
		20% Contingency
		Sales Tax (4% - Skagway)
		CONSTRUCTION SUBTOTAI
		Engineering Fees
		Permit Assistance Fees
		TOTAL

Table 2. Engineer's cost estimate for Taiya River engineered logjam project, option B (remove campground - large engineered logjams).

ITEM		DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL COST	REFERENCE
	e	Piling logs	EA	49	$500.00	$24,500	Supply from Sealaska Corporation
13		Aggregate Materials & Placement					
	a	Embankment	CY	44,307	$0.00	$0	Means, FE Loader, 300' Haul, Sand and Gravel, w/Alaska adjustment
	c	Topsoil Import	CY	2,640	$20.66	$54,527	Means Topsoil material only, plus Alaska adjustment
14		Planting - Sitka Spruce - 2 Gallon	EA	713	$58.00	$41,354	Vendor Quote (seed 'n' tree) plus $15/plant installation
15		Planting - Alders - 2 Gallon	EA	357	$19.50	$6,962	Vendor Quote (seed 'n' tree) plus $10/plant installation
16		Planting - Western Red Cedar - 2 Gallon	EA	357	$51.25	$18,296	Vendor Quote (seed 'n' tree) plus $15/plant installation
17		Planting - Shrub - Oregon Grape - 1 Gallon	EA	1,191	$8.35	$9,945	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
18		Planting - Shrub - red huckleberry - 1 Gallon	EA	1,191	$8.65	$10,302	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
19		Planting - bearberry - 1 Gallon	EA	1,089	$6.75	$7,351	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
20		Planting - yarrow - 1 Gallon	EA	1,257	$7.35	$9,239	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
21		Planting - mahonia repends - 1 Gallon	EA	972	$6.75	$6,561	Vendor Quote (seed 'n' tree) plus $2.50/plant installation
22		Vegetative Plantings - Live Stakes	EA	1,300	$2.00	$2,600	Vendor Quote (seed 'n' tree) plus $1.00/plant installation
23		Planting delivery - barge	EA	1	$14,100.00	$14,100	Vendor Quote
		SUBTOTAL				**$2,659,960**	
		20% Contingency				**$531,992**	
		Sales Tax (4% - Skagway)				**$106,398**	
		CONSTRUCTION SUBTOTAL				**$3,298,350**	
		Engineering Fees				**$109,465**	
		Permit Assistance Fees				**$101,490**	
		TOTAL				**$3,509,305**	

existing logging operations of southeast Alaska. The two most likely sources for logs with rootwads are from logging road clearing/construction and blowdown clearing. Because of the limited rate of supply, early cooperation with suppliers will be required to attain the proposed amount of logs with rootwads for construction during the 2003-2004 winter. Prices for the materials are derived empirically, rather than from experience: the raw material costs for the key, footer, and stacked logs (with rootwads) were based on the current market prices for the logs without rootwads, to which a premium of approximately 30% was added to account for the additional work presented by harvesting the rootwad.

- Delivery costs for the logs are based on conversations with Kent Halverson, of Boyer Alaska Barge Lines, Inc. As with the supply of logs with rootwads, the transportation and loading of these logs constitutes an uncertainty. Because of the physical size of logs with rootwads, it is estimated that only 200 to 250 could be placed on one of Boyer's 6,000-ton barges that would normally accommodate upwards of 1000 logs not having rootwads. Mr. Halverson estimated that it may take up to two days each to load and unload. The costs include the barge, a suitable tug, and a 150-ton crane, and crew. In addition, the costs include one mobilization and demobilization from Seattle to Skagway and back, assuming that all of the log materials will be available and ready for shipment within a few day's barge trip from Skagway. It was further assumed that, in the off-season, the docks and facilities at Skagway could be used for offloading of the barge.

- Placement of 16,800 cubic yards of embankment for option A and 32,700 cubic yards of embankment for option B for bioengineered (vegetated) bank stabilization between engineered logjams. The average height of the embankment will be 10 feet with average sideslopes at 3H:1V.

- Embankment materials will be supplied from materials excavated during construction of the engineered logjams. Additional material will be acquired from the existing river deposits (alluvium) located within the project site.

- Construction of a 600-foot long bypass channel approximately 10 feet wide with sideslopes at 3H:1V.

- Construction of a temporary 600-foot long access road will be required to transport supplies to the site. It is assumed that the road will be 40-feet wide, with 8 inches of import sub-base, and one log bridge over the temporary bypass channel.

- Logs to be transported by barge from one or multiple locations located within two-days barge trip from Skagway.

- Logs from landslide area are either too small and/or the rootwads are damaged and therefore cannot be used.

Data Needs

Several types of data and analyses are necessary or are recommended for design development leading to implementation of an engineered logjam bank stabilization project. These include the following:

- Detailed topography of the project site, surveyed channel cross-sections, and channel profiles of the lower Taiya River
- Measurements of sediment transport and sediment loading to be used with estimates for long-term alterations at the site
- Hydraulic modeling (HEC-RAS) of the project site for various bank stabilization alternatives, to predict floodplain reactions, storage and backwater effects, and flow deflection
- Wood debris budget and size of natural key logs
- Tide levels of the Taiya River inlet to be used as a boundary condition for hydraulic models.

Future Work

Final Design and Specifications

The design of instream structures is developed at two scales: i) individual structures and their components, and ii) placement with respect to the channel reach and other structures. Design plans thus include two sets of designs, one for individual structures and another for describing where each structure is placed within the project reach. Each set of plans should include analysis demonstrating that the engineered structures are likely to meet project objectives and constraints (Table 3).

Table 3. Engineered logjam design scales and associated plans and justification.

Design Scale	Plans	Justification
Individual structure	Construction drawings detailing individual log members and their locations within an engineered logjam	How does engineered logjam contribute to attaining objective(s) within project constraints? Does engineered logjam emulate natural analog for fluvial system? Do log members and the structure meet desired stability specifications?
Channel reach	Site drawings detailing engineered logjam locations within project reach	How do individual structures work with one another and within reach context? What is the potential range of channel change(s) resulting from engineered logjams, and are those changes within the range of historical change or the desired state of restoration? Will changes (not necessarily due to engineered logjams) in channel position adversely affect performance of the structures, either individually or collectively as a unit?

The general steps for designing an engineered logjam project include the following:

- Determine the bottom elevation for each engineered logjam
- Estimate the footprint elevation and height of each engineered logjam
- Determine the dimensions of each engineered logjam
- Estimate size specifications for key members, key footer logs, and stacked members
- Determine the number of structural members in each engineered logjam
- Provide guidance on preferred tree species for structural members
- Determine engineered logjam positions, spacing, and quantity needed.

Environmental Review and Permitting

National Environmental Policy Act (NEPA) compliance is required for the project, both because it has federal funding and because it requires a federal permit. Neither allocation of funds nor issuance of permits may occur before the NEPA review process is completed. The project does not appear to meet the criteria for categorical exclusion under NEPA, and the project is expected to be accomplished without significant adverse impacts; therefore the appropriate NEPA document appears to be an environmental assessment. The National Park Service, as the lead agency for NEPA, would make this determination and would conduct the NEPA review in cooperation with the U.S. Army Corps of Engineers, which has regulatory authority over the project. The National Park Service guidance for preparation of environmental documents (DO 12) requires an environmental assessment to follow the same format as an environmental impact statement, although the analysis can be abbreviated.

An environmental assessment must analyze a wide range of issues; in this case the issues requiring the greatest effort are potential impacts associated with soil erosion, water quality, safety and recreation, fish habitat, and historic and cultural resources. The environmental assessment would evaluate alternative methods of meeting the project objectives, including, at a minimum, the two options discussed above. Preparation and review of the environmental assessment can be expected to require 6 to 8 months, depending on the approach taken with regard to agency coordination and public comment.

The National Park Service is required to produce a finding of no significant impact (FONSI) (assuming that the adverse environmental impacts are not found to be significant).

Compliance with section 106 of the National Historic Preservation Act is required and should be coordinated with the state historic preservation office. Because preservation of historic and cultural resources is a central purpose of the project, and the National Park Service has a great deal of expertise in this area, compliance with section 106 is not expected to pose difficulty.

Compliance with the federal Endangered Species Act is also required. According to recent information obtained from the U.S. Fish and Wildlife Service and National Marine Fisheries Service websites, no species that are listed as threatened or endangered use the Taiya River. This will be confirmed and documented in the environmental assessment.

A Clean Water Act section 404 permit from the Corps of Engineers is required for the project. After application, this permit takes approximately 3 months to obtain. A pre-application conference is required, and the environmental assessment must be completed before a permit can be issued. The permit can be pending while the environmental assessment is being prepared. The permit process should also confirm the allowable construction timeframe, based on minimizing adverse impacts on fish and water quality. It is not anticipated that a separate biological assessment will be necessary, because no endangered species will be affected.

A Title 16 fish habitat permit from the Alaska Department of Fish and Game is required. This permit, as well as certifications for Clean Water Act section 401, essential fish habitat, and coastal zone management, are obtained by completing a coordinated permit questionnaire, which provides all state agencies with the information needed to complete their reviews. With advance notice, these agencies can be included in the pre-application conference with the Corps of Engineers.

In summary, the environmental review process will require 6 to 8 months. Permit review could take an additional 3 months, although this timeframe may be shortened through pre-application coordination.

Construction

Engineered logjam projects involve a complex construction process. In southeastern Alaska, constructing engineered logjams may be a completely new experience for the contracting community. It is especially critical that a site visit be included as a normal part of bid solicitations. It may also be desirable to invite prospective bidders and partners to attend an educational workshop or meeting, to acquaint interested parties with the techniques and requirements of engineered logjam construction.

Substantial preparations by the National Park Service are necessary prior to the solicitation process. Potential contractors must be informed of the source of construction material, locations of staging areas, specific construction site locations, and the like. Contractors must be educated on project expectations and objectives, the construction process, construction requirements and tolerances, general equipment requirements, and special items to be provided by the contractor such as cofferdams, stream diversions, and dewatering plans.

The engineered logjams proposed for the Taiya River site would need to be constructed together during one season; construction could not be phased over multiple seasons or years. Construction of the logjam structures described in this memorandum could take 4 to 8 weeks, depending on the option chosen and other factors. Due to the unique character of this project, a preconstruction meeting between the National Park Service, the design engineers, and the contractor is highly recommended. The design engineers should also be present during construction to provide oversight on project implementation.

Construction of instream structures is analogous to major surgery, in that it is intrusive and may be alarming to passing observers, so it should be performed as quickly as possible. The long-term benefits of a well-designed and constructed project far outweigh the short-term impacts associated with construction. After the first bed mobilizing or bankfull event, there is likely to be little permanent evidence left of the disturbance other than the logjam structures. In the case of all engineered logjams constructed to date (Abbe 2000), there is little to reveal their artificial origins.

Monitoring

Monitoring should be performed for several years following construction to determine whether minor adjustments are needed to the engineered structures, and to assess whether additional structures should be built. Shoreline erosion should be measured annually, and trends in channel migration should be systematically reported. Erosion monitoring should be performed on the ground and from aerial photographs. The engineered logjams should be inspected after peak flow events (e.g., equal or exceeding the 1-year recurrence flow). More thorough inspections should be conducted at least once during winter low flows, with the condition of the structures, observed scour, sedimentation, and revegetation all reported in an annual performance report (including repeatable photo stations, geomorphic maps, and structure maps). A wood budget should be completed over several years to document changes in wood loading, wood debris accumulation on the structures, or wood loss.

Conclusion

The brief geomorphic assessment of the lower Taiya River provided in this memorandum identifies logjams as a key geomorphic element, setting the precedent for use of engineered logjam technology for river bank stabilization. An engineered logjam strategy for bank protection at the Dyea town site offers a beneficial solution to the ongoing erosion problem, without compromising the natural resources of the lower Taiya River.

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APPENDIX A

General Specifications

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Logs

Key members form the foundations of stable logjams in nature and are the single most important component of any engineered logjam. Key members are the largest logs in a jam and must retain a large rootwad. Key footer logs act as lateral restraint that reduces the risk of key members falling out from the outer margins of an engineered logjam. General specifications for the logs are minimum 60 to 70 feet in length and 3 feet in diameter with attached rootwads. The length should be three times the diameter of the rootwad. Preferable species are Sitka spruce and western hemlock, although large cottonwoods can be used.

Stacked members act to increase the height of an engineered logjam, supplementing the height of key member rootwads. Stacked members also add structural integrity to the structure by forming an interconnected assemblage of log layers anchored within the bed or bank. By increasing the log surface area buried beneath alluvium, stacked members increase the total load exerted on the underlying key members. Stacked members have rootwads and are similar in size or slightly smaller than key members. The length of stacked members should be equivalent to the desired width of the logjam structure (40 to 75 feet).

Racked member tree boles are analogous to the debris that floats up against a natural logjam and forms a large pile, resembling the visual chaos typically associated with logjam images. Racked members are the smallest and most plentiful logs used in an engineered logjam. Typically, 100 racked members may be used in a single structure (depending on the size of individual logs). They must be large enough that they cannot pass through interstitial spaces between the key members, but otherwise there is no limitation to their size. Racked member length can also be variable but it is preferable to have lengths equal to the width of the logjam structure.

Backfill

A component of engineered logjam structures is backfill. The key and stacked members of the completed structure are buried in alluvium. Rock may be used if alluvium cannot be retained within the logjam or if additional ballast is warranted. Some advantages of backfilling the structure include i) adding significant surcharge weight to the structure, thereby increasing its stability and factor of safety values; ii) using alluvium excavated for the footprint in a cost-effective way (i.e., no hauling); and iii) accelerating riparian forest recovery by creating a surface that can be planted or is more conducive to natural revegetation after construction. Generally, the volume of the excavated bed material alluvium should be sufficient for backfill. Backfill should not be placed on racked logs at the upstream end of an engineered logjam.

Riparian Reforestation

As soon as possible after construction, the top surface of each engineered logjam should be planted with native riparian vegetation. Trees provide root cohesion to the alluvium, as well as floodplain roughness to reduce overbank flow velocities and surcharge on the structure, and eventually they provide a new source of wood for maintaining the structure. Because key members are the most important part of an engineered logjam and they are the most difficult and most expensive to obtain, reestablishing the potential to recruit future key members is a long-term priority.