COCKREHAM ISLAND ALTERNATIVE IDENTIFICATION AND QUALITATIVE ASSESSMENT FINAL REPORT

Submitted to:

Skagit County
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Submitted on:

July 15, 2008

File 21617

nhc

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Executive Summary

Cockreham Island lies in the Skagit River floodplain between River Miles (RM) 39 and 35 or between the towns of Hamilton and Lyman. Skagit County, in cooperation with other agencies and local landowners, is considering a number of different options or alternatives for Cockreham Island, including buying private lands.

The County also maintains flood and erosion protection works near the Island, including the Cockreham Dike on the upstream end of the Island on the right bank of the Skagit River and revetment along the South Skagit Highway opposite the Island. Skagit County contracted with Northwest Hydraulic Consultants to evaluate the maintenance, upgrades or new structures that might be required for flood and erosion protection if the alternatives were implemented and also identify other obligations or impacts that might result from implementation. Our evaluation was qualitative and is summarized in Table 3. We also briefly considered the engineering analyses or studies that might be needed to carry the alternatives through to design and implementation.

In order to evaluate the consequences of the different alternatives proposed for Cockreham Island on the County's facilities and programs, it is necessary to predict the future behavior of the Skagit River near Cockreham Island and its potential response to the alternatives. We relied on past behavior, as expressed on historic maps and air photos, to predict future behavior. In projecting future behavior we considered the human influences on the Skagit Watershed and the Skagit River near Cockreham Island that have occurred over the past 120 years.

The report examined four alternatives for Cockreham Island: three were developed by the County and their partners; the fourth was developed for this report. Some of the alternatives depend on buy-out of property on Cockreham Island to be feasible. They were:

- Alternative 1: Remove Emergency Extension of Cockreham Training Dike
- Alternative 2: Partial Removal of Training Dike; New Channel Across Island
- Alternative 3: Jim's (sometimes called Etach) Slough Flow Split
- Alternative 4: Abandon Cockreham Training Dike; Protect Lyman-Hamilton Highway

Alternative 1 essentially restores the training dike to the conditions of 2004 and 2005, re-creating the flooding and erosion conditions that prevailed then. It is a baseline alternative that provides a useful comparison for the other three.

The alternatives proposed by the County and their partners all will require continued maintenance of at least part of the Cockreham training dike and Alternatives 1 and 3 require maintaining the revetment along the South Skagit Highway. In fact, the functioning of Alternatives 2 and 3 depends on maintaining the training dike in its current alignment and we would recommend upgrades to the training dike, given its importance to these alternatives. Upgrades would also be appropriate along the South Skagit Highway for Alternative 3. All these alternatives have impacts on other features. Alternative 1 will result in some damage to farm fields on Cockreham Island; Alternative 3 requires a new culvert and upgrades along Jim's Slough to prevent flooding. Alternative 2 potentially has very significant impact on the Skagit

River, causing channel instability, erosion and flooding in the vicinity of Day Creek, Lyman and downstream and adjustments progressing upstream towards the City of Hamilton.

The fourth alternative would be to abandon the Cockreham Training Dike and construct a new line of erosion defense along the Lyman-Hamilton Highway or State Route 20. Such an alternative would eliminate maintenance and repair at the training dike but would result in more frequent flooding of the northeastern part of Cockreham Island and, possibly, also of the area towards Lyman. Maintenance and repairs would be slightly reduced along the Skagit Highway, depending on the flow diverted across Cockreham Island. In the longer-term, the Skagit River may avulse across Cockreham Island, resulting in some of the consequences described for Alternative 2.

This investigation is not intended to provide an exhaustive list of possible alternatives, but rather begin to build a scientific foundation from which alternatives can be evaluated. Before moving forward with further alternative identification and analyses, we recommend that the County complete two tasks. First, the County should determine which portions of Cockreham Island it *realistically* will be able to acquire. This will ultimately dictate the range of possible alternatives.

Second, if there is serious consideration of Alternatives 2, 3 or 4, we recommend that the County proceed with the construction of a two-dimensional model of the project reach. The model would first be used to document existing hydraulic conditions across the island for a range of flood events. Once the model has been built, it can be used to help identify and refine the alternatives so that they maximize County benefits and minimize future uncertainty, risk, and cost.

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1. INTRODUCTION

Background

Cockreham Island lies in the Skagit River floodplain between River Miles (RM) 39 and 35 or between the towns of Hamilton and Lyman (Figure 1). Skagit County has maintained a training dike or training along the right bank of the Skagit River on the upstream end of the island since the 1950s (Figure 1). The dike prevents the river from migrating across the Island but it provides only limited flood protection, and it has breached or been bypassed during recent floods. The County also maintains revetment along the South Skagit Highway, on the left bank of the Skagit River across from the Island. Over the years, the County has spent considerable effort and funds maintaining both these structures.

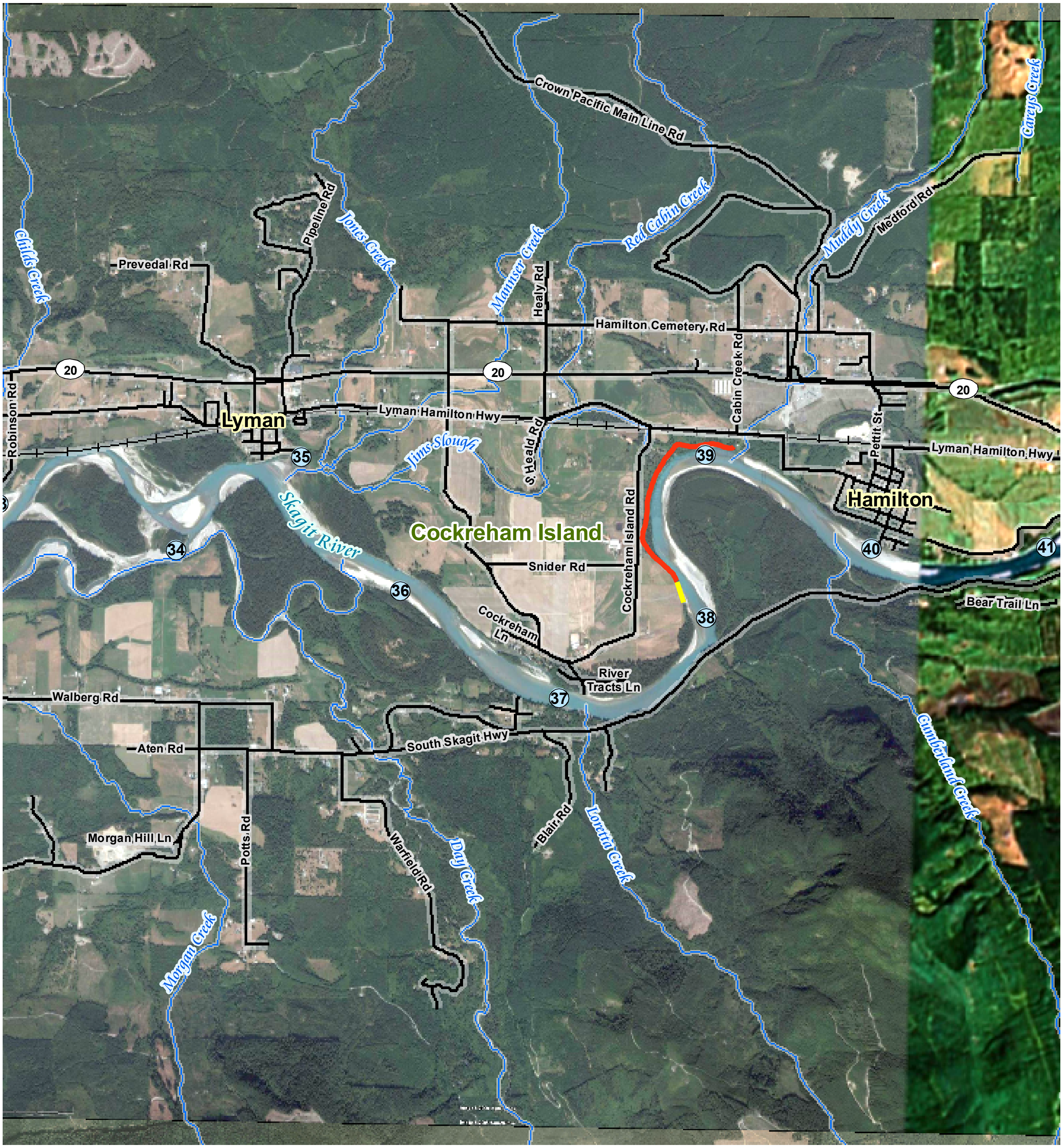
The County, in cooperation with other agencies and local landowners, is now considering a number of different options for Cockreham Island. A study funded by the County examined the feasibility of buying out existing landowners, removing part of the training dike, and improving or enhancing salmon habitat by directing the Skagit River across the Island in a new channel (GeoEngineers 2007). Based on the conclusions of the GeoEngineers study, funds for alternatives analysis and design of salmonid habitat enhancement at Cockreham Island are now being pursued by the County and their partners.

Skagit County Department of Public Works is reviewing their flood and erosion protection program for the Skagit River near Cockreham Island and also considering the consequences of the different alternatives on the existing structures and on their maintenance responsibilities. To help with the review, the Department has contracted Northwest Hydraulic Consultants (**nhc**) to provide river engineering services to predict the likely future behavior of the Skagit River, its response to the different alternatives under consideration, and the potential consequences for Public Work’s programs.

Objectives and Approach

The overall objective of this report is to evaluate the maintenance, upgrades or new structures that might be required for flood and erosion protection and identify other obligations or impacts on the County that might result from implementation of the different alternatives. The report also briefly describes engineering analyses and studies that might be needed to carry the alternatives through to design and implementation. **nhc**’s study is preliminary and is based on a brief field reconnaissance, discussions with the County, a review of previous studies and existing information, and analysis of historic maps and air photos.

In order to evaluate the consequences of the different alternatives proposed for Cockreham Island on the County’s flood and erosion control program, it is necessary to predict the future behavior of the Skagit River near Cockreham Island and its potential response to the different alternatives. This is not a simple task. We have relied on past behavior, as expressed by comparing sequential historic maps and air photos, to predict future behavior. However, the past behavior of the river is not always a complete guide to future behavior because of human modifications to the Skagit Watershed and to the Skagit River near Cockreham Island. We reviewed existing reports and studies to understand the anthropogenic changes that have

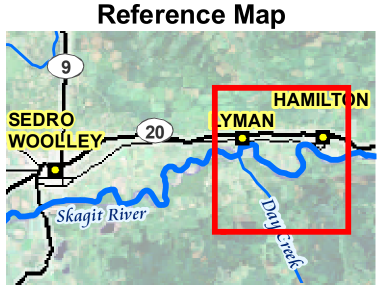


Data Sources: Google Earth Imagery, 2008. Skagit County Roads, 2008. Skagit County Streams, 2003.

Legend

- Streams
- Major Roads
- Railroad
- Cockreham Dike
- Dike Extension (2005)
- (40) USGS River Miles

Reference Map



Cockreham Island Alternative Assessment

Cockreham Island at Skagit River: Location Map

Scale - 1:48,000 1 inch equals 4,000 feet

0 2,000 4,000 8,000 Feet

N E S W

WA State Plane, Zone North	NAD 27	Survey Feet
northwest hydraulic consultants	project no. 21617	June 30, 2008

Figure 1 - Cockreham Island at Skagit River: Location Map

occurred in the Skagit Watershed. This understanding was then combined with an analysis of the historical behavior of the Skagit River in order to predict future behavior and the likely responses to the alternatives that are proposed for Cockreham Island.

The next chapter of this report briefly describes historic and current conditions in the Skagit Watershed, emphasizing hydrology, sediment supply and local modifications to the river, as these are most directly connected to river behavior. The third chapter of the report describes the historical behavior of the Skagit River near Cockreham Island and identifies important trends that can be applied to predict future behavior. The fourth chapter then describes the alternatives proposed for Cockreham Island, considers the potential response of the Skagit River, and evaluates potential impacts on the County's maintenance and other responsibilities.

2. SKAGIT WATERSHED AND RIVER OVERVIEW

The Skagit River, and particularly the Middle Skagit River, has been the subject of several recent studies. Collins and Sheikh (2002; 2003), R2 Resource Consultants (2004), GeoEngineers (2007) and **nhc** (2007) have examined aspects of geology, geomorphology, hydrology, hydraulics or sediment transport that are relevant to understanding the Skagit River. The following sections provide an overview of the Skagit Watershed, emphasizing human modifications to the watershed that might affect the Skagit River. The discussion focuses mostly on quantifying changes that have occurred in hydrology and sediment supply over time, as a result of reservoir projects. We also discuss human modifications to the Skagit River near Cockreham Island.

The goal of the overview is to provide a context for interpreting the observed changes along the Skagit River near Cockreham Island that are described in Chapter 3 and projecting potential future behavior with the proposed alternatives in place.

Physiography

The Skagit Valley was ice-covered during the Fraser Glaciation and the most recent glacial deposits are those left by the Vashon continental ice sheet stade. These deposits mantled valley walls, filled part of the valley, and blocked the Skagit Valley near Concrete. Radiocarbon dating indicates that these deposits were rapidly incised by the Skagit River post-glaciation. Volcanic mudflows or lahars that originated from Glacier Peak later filled the Skagit Valley and are thought to have diverted the upper Sauk River from the North Stillaguamish watershed to the Skagit River near Darrington (Dragovich *et al* 2000; Tabor *et al* 2004). The lahar deposits have since been incised by the Skagit River and they now form terraces along the side of the valley that confine some reaches of the Middle Skagit River (see Collins and Sheikh 2003).

GeoEngineers (2007) reported that the form and profile of the Skagit Valley changed near Cockreham Island (Figure 1). They observed that the valley bottom and floodplain broaden downstream of Hamilton and that the valley slope also appears to decline near there. Certainly, the valley widens but it is difficult to confirm the change in valley slope from the diagram provided by GeoEngineers (2007; their Figure 6) as it is based on relatively few points extracted from USGS quadrangle sheets. Water surface profiles surveyed at low discharges (USACE 1911) show a decline in slope near Sorensen's Bend (about three to four river miles downstream of Lyman) but none between Hamilton and Lyman.

However, the morphology and behavior of the Skagit River does seem to change near Hamilton (R2 Resource Consultants 2004; GeoEngineers 2007). Upstream of Hamilton, the Skagit River is partly confined, stable, and slightly sinuous. Downstream of Hamilton, the Skagit River is sinuous, mostly unconfined and prone to channel shifting through meander migration, meander growth, chute cutoffs and avulsion. The evidence for frequent channel shifting includes islands, old channels, sloughs and other floodplain features. Such a channel pattern can be described as "wandering" and it is reasonably typical of large, active gravel-bed rivers in the Pacific Northwest. The exact point where the channel behavior changes has not been determined but the historic channel shifting described in the third chapter of this report suggests that it is near the upstream end of Cockreham Island.

As described in the next two sections, dam and reservoir construction for hydro-electric power and other benefits have altered peak flows and sediment supply to the Skagit River. Other human impacts that may have affected the Skagit River include headwater logging, with potentially increased peak flows and coarse sediment supply, clearing of floodplain forest and riparian trees and clearing or removal of logjams. The last two impacts may have been particularly important to channel morphology near Cockreham Island at the start of the 20th century.

Hydrology

R2 Resource Consultants (2004), GeoEngineers (2007), Mastin (2007) and **nhc** (2007) provide background information on the hydrology of the Skagit River. Their studies have focused on the USGS gage "Skagit River near Concrete (12194000)", which is the nearest gage to the Cockreham Island reach. The gage began operation in 1925, but its record includes four historic floods that occurred between WY 1898 and 1922, all with estimated peak discharges greater than 220,000 cfs. Annual peaks in the 80 years of gage operation have not even approached the historical peaks, even after the effects of flow regulation have been removed (see **nhc** 2007). There is some uncertainty in the discharges estimated for the historic flood peaks (**nhc** 2007 provides ranges); however, it seems likely that they were larger than contemporary floods and that they had a profound effect on historical channel morphology (Chapter 3).

The Skagit River has a long history of regulation by dams and reservoirs constructed for hydroelectric generation or other purposes and the flows at the Concrete gage are affected by five reservoirs, all built at different times. The lower project on the Baker River (Shannon Reservoir) was built in 1929; the upper project (Baker Reservoir) was completed in 1959 (GeoEngineers 2007). The impact of the Baker River projects on the hydrology of the Skagit River is discussed in detail by R2 Resource Consultants (2004). There are also projects on the upper Skagit River. Gorge Dam, about 40 miles upstream of Concrete, was first built in 1924; it was re-built in 1961. Further upstream, Diablo Dam was built in 1930 and Ross Dam was constructed between 1940 and 1953.

Flow regulation can have a significant impact on channel morphology by altering the magnitude of frequent or channel-forming peak flows. Unregulated annual peaks were calculated by the Corps of Engineers for 1944 to 2006 at the gage near Concrete (some years missing; see **nhc** 2007). The mean annual flood calculated for the re-constructed record was 91,000 cfs; for the same years under regulation, it was 81,000 cfs. This suggests about an 11% decrease in the magnitude of the frequent peak flows over the past sixty years compared to earlier years. The potential impacts of the reduced flows on morphology are briefly discussed in the concluding section of this chapter.

Sediment Transport

The sediment load of the Skagit River can be divided into a suspended load, consisting of fine material carried in the water column, and a bed load, consisting of coarse material that rolls, slides or hops along the channel bottom. Generally, bedload or bed material transport is considered to be intimately connected to channel morphology; suspended sediment transport less so. Bedload transport is difficult to measure and there are no direct measurements on the Skagit River. Given the lack of direct measurements, bedload transport was estimated by indirect means, as discussed below and in following sections.

R2 Resource Consultants (2004) provided a suspended sediment rating curve for the Skagit River at Mount Vernon gage (12200500) constructed from suspended sediment concentrations measured by the USGS. They applied this rating curve to mean daily flows from 1940 to 2001 and calculated an annual suspended load of 1.2 million tons. Prorating the estimate at Mount Vernon by watershed area suggests that the annual suspended load at the Concrete gage would be about 1.06 million tons. R2 Resource Consultants state that the Mount Vernon estimate is unlikely to be accurate, and is likely to be too low, since the rating curve is based entirely on concentrations measured at flows less than 42,000 cfs.

Based upon the estimates above, the annual suspended sediment yield for the Skagit River watershed is 390 tons/mi^2. This was calculated from the 3,093 mi^2 watershed at Mount Vernon and reflects existing conditions in the watershed with the dams and reservoirs discussed earlier mostly in place. To put this into a regional context, it is much lower than the 980 tons/mi^2 estimated for the Nooksack River at Deming (R2 Resource Consultants 2004) or the 1,100 tons/mi^2 estimated for the Stillaguamish River near Silvana (**nhc** 2004).

An estimate of the unregulated or "natural" suspended sediment load can be derived from the one based on regulated conditions. R2 Resource Consultants indicated that 1,450 mi^2, or a little less than half of the watershed area at the Mount Vernon gage, lie upstream of the Baker and upper Skagit project reservoirs. While some sediment passes through these reservoirs, most of the annual suspended load arrives from the unregulated or "natural" portion of the watershed. R2 Resource Consultants (2004) estimated the suspended sediment passing through the reservoir projects based on their sediment budget for the Baker Projects and subtracted that from the regulated total to obtain an unregulated annual suspended load of about 1,000,000 tons. This is equivalent to a yield of 625 tons/mi^2, as calculated for the 1,653 mi^2 unregulated watershed area. Applying the above yield to the watershed area at Concrete predicts an unregulated annual suspended sediment load of about 1.7 million tons there. When compared to the Nooksack and Stillaguamish sediments yields, such an estimate may still be too low.

R2 Resource Consultants estimated bedload on the Nooksack as 15% of suspended load and applied this percentage to the Baker River Watershed. In our view, this percentage is too high for the Skagit River. Bedload on the Snohomish River near Monroe was determined to be 5% of suspended load (Collins and Dunne 1990); on the Stillaguamish River near the I-5 Bridge it was estimated to be 2% of suspended load (**nhc** 2004; Collins 1992). However, such values may be too low for the Skagit River near Concrete. Instead, we have assumed that bedload is between 5 and 10% of suspended load, with the upper end of the range partly compensating for the low estimate of suspended load.

Based on the regulated suspended load estimated for the Skagit River at Concrete, annual bedload transport with the various reservoirs and power generation projects in place might now be about 50,000 to 100,000 tons. Based on the unregulated suspended load estimate for Concrete, annual bed load transport might have been 85,000 to 170,000 tons prior to reservoir construction in the 1920s. Current conditions then represent about a 40% reduction of average bedload transport, or a reduction of about 35,000 to 70,000 tons. R2 Resource Consultants provided a preliminary sediment budget for the Baker Watershed based on some sediment transport calculations, sediment yields and transfer of measurements from the Nooksack Basin that helps confirm the above estimates. Their budget indicates that bedload transport to the Skagit River has been reduced by 20,000 to 30,000 tons per year by the Baker River projects. Assuming that the bedload captured by the Upper Skagit projects is about the same amount, bed load transport on the Skagit River might have been reduced by 40,000 to 60,000 tons or about the same as estimated from the suspended load measurements. As discussed below, significant reductions in both suspended and bedload sediment transport rates can, over time, affect channel morphology.

Floodplain Modifications near Cockreham Island

nhc (2007) described some of the structures that have been built in the floodplain of the Skagit River near Cockreham Island (Figure 1). Roads include Highway 20, which was built in the 1950s; the Lyman-Hamilton Highway which was built before 1900; and the South Skagit Highway. The Great Northern Railway, which was built before 1900, has now been converted to a trail. The first two roads and the railway are on the north side of the floodplain and are mostly distant from the river. The South Skagit Highway is on the south side of the floodplain. It abuts the Skagit River where it crosses a narrow section of floodplain at the base of the south valley wall. Along this section, the bank is steep and is protected by revetment of varying age and quality, including several recent repairs.

It is not known when Cockreham Island was first cleared for farming but the 1911 river survey (USACE 1911) notes “ranches” on Cockreham Island and on the left (south) bank, farmhouses near the edge of the right bank, a ferry cable, and the Miller Logging Company downstream of Lyman. These notes suggest that the island had been cleared or partly cleared by the start of the 20th century and that riparian trees may have been partly removed. Such modifications generally result in reduced bank strength that can increase the erosion that occurs during floods. While not documented, logjams in this part of the Skagit River may have been cleared for navigation improvements. If so, the clearing may also have contributed to accelerated shifting and erosion during floods.

The main flood control structure in the reach is the Cockreham training dike, which was first built in the 1950s and now extends for about 6,600 feet along the outside or concave bank of the RM 39 bend, just downstream of Hamilton (see Figure 1). The dike has fixed the right or concave bank of this bend of the Skagit River in place since it was constructed. **nhc** (2007) and USACE (2007) shows that the training dike has a crown width of about 20 feet, 2:1 waterside slopes and a crest elevation that is about 6 to 8 feet above local ground. The waterside face of the dike and bank is revetted but failures have been fairly common and further repairs are planned to about 700 feet of the waterside toe with PL 84-99 funds in 2008 or 2009 (USACE 2007). The repairs also include about 1,000 feet of seepage berm on the landslide of the training dike starting about 1,000 feet from the upstream end.

The training dike has been repaired and upgraded several times since it was built and it was extended about 600 feet downstream as part of flood fighting in 2005. The County now plans to remove this extension.

Implications for the Skagit River

As discussed above, the Skagit River near Cockreham Island is now affected by human modifications of hydrology and sediment supply and, in the past, by a series of large floods, by clearing of floodplain forest and, possibly, removal of logjams. These factors affect the morphology of the Skagit River and need to be kept in mind when interpreting historical maps and air photos of the Skagit River near Cockreham Island. They are summarized below:

1. The succession of four unusually large floods from 1898 to 1922. These floods will have resulted in channel enlargement, increased rates of erosion or shifting, and increased coarse sediment transport

2. The reduction in peak flows and coarse sediment supply (particularly from the Baker River) after about 1930 or so. The changes predicted for the Skagit River are reduced channel width; lower slope; shorter meander wavelengths; and increased sinuosity (see Kellerhals and Church 1989 for a discussion of why this occurs). Bed material may coarsen or fine, depending on the relative reduction of peak flows and bed load. On the Skagit River, where the reduction in coarse sediment supply has been more significant than the reduction in peak flows, it might be expected to coarsen (see also GeoEngineers 2007). The reduced peak flows and coarse sediment supply will also reduce existing rates of erosion and channel shifting to less than historical ones.

   The changes to channel width from reduced peak flows alone are fairly subtle. The reduced width that might have resulted from the reduced peak flows can be estimated from the commonly observed relationship between bankfull width and the square root of the channel-forming flow. This relationship predicts that the ratio of the "regulated" to "unregulated" width, w_r/w_u, is proportional to $(Q_r/Q_u)^{0.5}$, where Q is the channel-forming flow and the subscripts "r" and "u" refer to "regulated" to "unregulated". With peak flows reduced by 11%, as described earlier, widths are only expected to have contracted by about 6% since the 1930s. Larger reductions in channel width are then explained by other factors, such as reduced coarse sediment supply or flood control works.

3. Forest harvesting of steep terrain in the upper Skagit Watershed. Such harvesting may have resulted in increased peak flows or subsequent landslides may have contributed coarse sediment to the Skagit River. The significance of historical forest harvesting on the Skagit River is not known and no references were found that document impacts.

4. Local modifications to the river and floodplain, such as floodplain clearing, removal of riparian trees and removal of logjams. While the timing and extent of floodplain clearing and removal of riparian vegetation are not known, it likely occurred in the late 19^{th} century and may have contributed to a wider, less stable channel during the large floods discussed above.

5. Construction of the Cockreham training dike, which has prevented migration of the RM 39 bend since the 1950s with impacts on the river cross section through the bend and on upstream water levels, as described in **nhc** (2007).

3. SKAGIT RIVER NEAR COCKREHAM ISLAND

This chapter describes the historical morphology and behavior of the Skagit River near Cockreham Island from previous studies and from maps and air photos and interprets the observed changes in the context of the modifications to the watershed and river described earlier. The final section describes trends that are helpful for predicting or projecting future river behavior with the various alternatives in place.

Previous Studies

nhc (2007) described the changes that have occurred along the Skagit River immediately downstream of Hamilton, by comparing bank lines interpreted from historical maps and air photographs. For this investigation, the bank lines have been extended downstream of Lyman and bank lines for 1994 and 2006 have been added (Figure 2).

The **nhc** (2007) report recommends caution in interpreting channel behavior because the bank lines were defined differently for the various years and because it was difficult to georeference the early surveys, particularly the 1911 Corps survey. Collins and Sheikh (2002) also discuss the difficulties in interpreting the earlier maps. Despite these cautions, the historic bank lines allow conjecture about the long-term behavior of this reach of the Skagit River that can help project or predict future behavior.

Historical Channel Geometry

nhc (2007) observed that average channel widths in the two miles of the Skagit River downstream of Hamilton have varied considerably over the past 120 years. Table 1 updates the channel geometry for the reach from Hamilton to downstream of Lyman as calculated from the bank lines shown on Figure 2. Channel length is measured along the center of the main channel; channel width is the total surface area of the channel between the banks (generally defined as the edge of permanent vegetation and including flood channels) divided by the channel length; sinuosity is the channel length divided by the valley length. Table 1 also provides an estimate of the average annual erosion rate for each time period. Average annual erosion is calculated as the area of floodplain lost between two sets of bank lines divided by the later channel length and the number of years between the sets of bank lines.

Table 1: Channel Geometry from Hamilton to Lyman: 1886 to 2006

Year	Channel Length (ft)	Average Width (ft)	Sinuosity	Average Annual Erosion (ft/year)
1886	43,600	800	1.44	-
1911	40,200	1,130	1.33	27
1937	41,200	1,140	1.36	16
1994	42,500	820	1.40	5
2001	42,000	800	1.39	12
2006	42,000	870	1.39	18

Significant geometric changes occurred from 1886 to 1911 when the Skagit River widened and shortened its course by 3,000 feet. The Skagit River remained wide until at least 1937; since then it has narrowed by about 30%, to about its 1886 width, as the channel has adjusted to the smaller

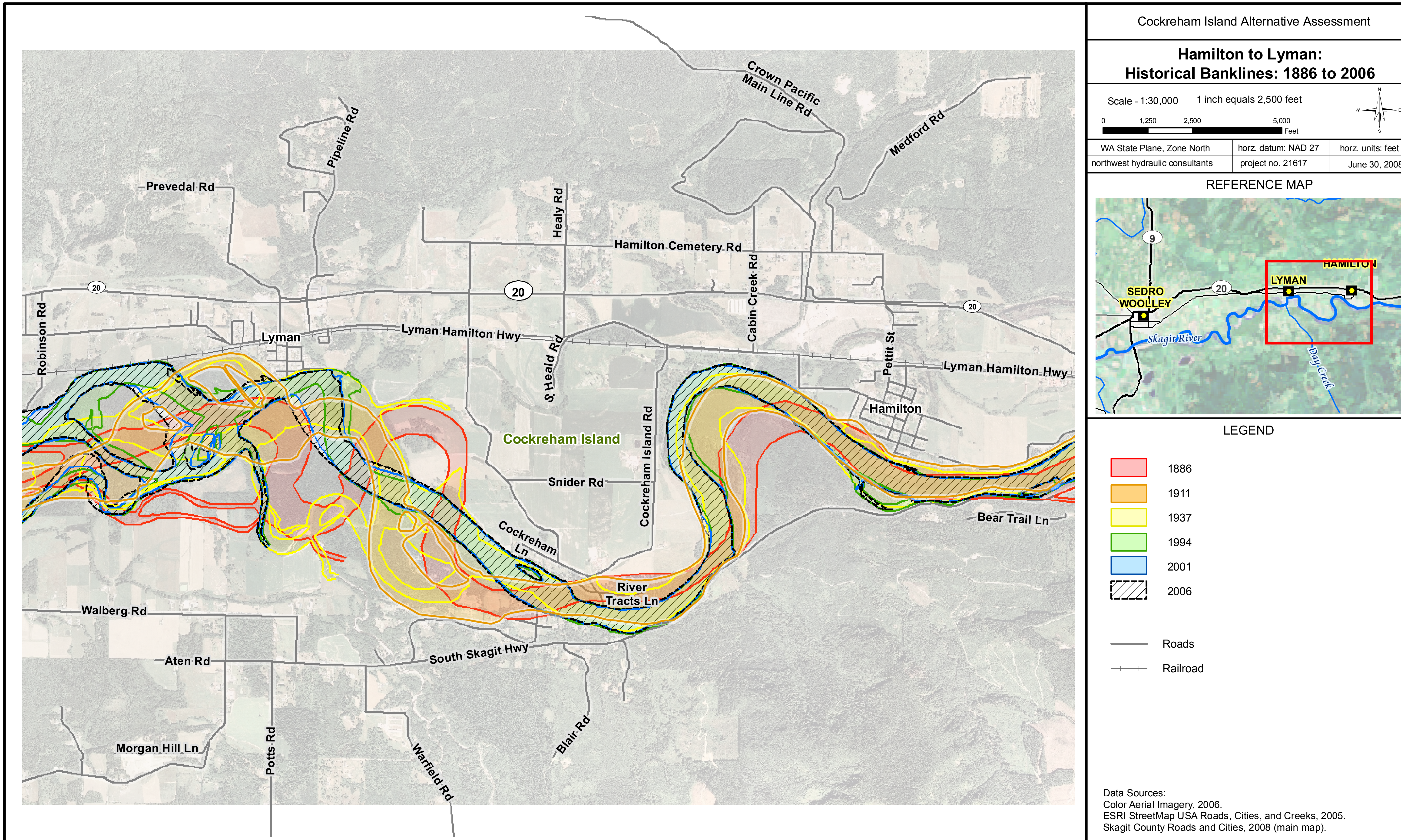


Figure 2 - Hamilton to Lyman Historical Banklines: 1886 to 2006

peak flows and other altered conditions in the watershed. The narrowing has been much greater than would be expected to occur just from the reduction in peak flows alone (Chapter 2), implying that part of the narrowing is recovery from the unusually large peaks between 1898 and 1922, and perhaps from floodplain clearing, as well as reduced widths from reduced coarse sediment supply,. Some of the channel narrowing has also occurred in response to the Cockreham training dike; this is discussed further in the next section.

We interpret the channel widening after 1886 as resulting from the large historic floods in 1898 and 1909, possibly aggravated by removal of floodplain forest and logjams and increased coarse sediment supply; the very wide channel was then maintained by the subsequent large floods in 1917 and 1922.

The highest erosion rates occurred between 1886 and 1911; the lowest from 1937 to 1994 (Table 1). As shown on Figure 3, the sites where channel shifting or bank erosion are concentrated have gradually shifted downstream since 1911. Between 1886 and 1911, erosion occurred along most of the Cockreham Island reach, between 1911 and 1937 it was concentrated near the middle of the reach and by 1994 to 2006 nearly all the erosion was in the vicinity of Lyman.

Historical Behavior of Skagit River

Cockreham Island Flood Channels

Jim's (also called Etach) Slough, to the north of the existing river, seems to be an infilled, old channel that dates to some time well before 1886 (Figure 4). This alignment once provided a much shorter river course than currently occurs between Hamilton and Lyman. The margins of the slough on recent air photos (which may represent the old concave banks) show a pattern of three meanders along this old channel with an average wavelength of 4,000 to 5,000 feet, about the same as the meander wavelengths that are shown on the 1886 historical map. The elevation shading of the LIDAR topography on Figure 4 clearly identifies other old flood channels across Cockreham Island and shows the remnant meander from the 1886 alignment on the southwest corner of Cockreham Island (see Figure 2).

Hamilton to South Skagit Highway Subreach (RM 40 to 37)

Since 1886, the Skagit River has entered the RM 39 bend downstream of Hamilton and then flowed south towards the limit of the valley at the RM 37.5 bend, where it turned west along the southern edge of Cockreham Island. By 1911 the RM 37.5 bend had migrated south to reach the valley wall and South Skagit Highway and it has remained in this alignment since, effectively prevented from growing or migrating by the valley wall and revetment that protects the highway.

The RM 39 bend enlarged and migrated downstream from 1886 until the Cockreham training dike was built. Between 1886 and 1911, the bend apex migrated about 1,500 feet (average rate of about 60 feet per year); from 1911 to 1937, it migrated another 300 feet (average rate 12 feet per year) and then after 1937 it migrated about 400 feet to reach the training dike alignment (20 feet per year, assuming the dike was built in the mid-1950s). The decline in migration rate after 1911 is interesting, particularly since two of the large historical floods occurred between 1911 and 1937 and the Baker Projects had not yet cut off coarse sediment supply from the Baker River. This will be addressed in a later section but potential explanations include reduced bedload transport from upstream, an over-wide bend following the earlier migration and storage

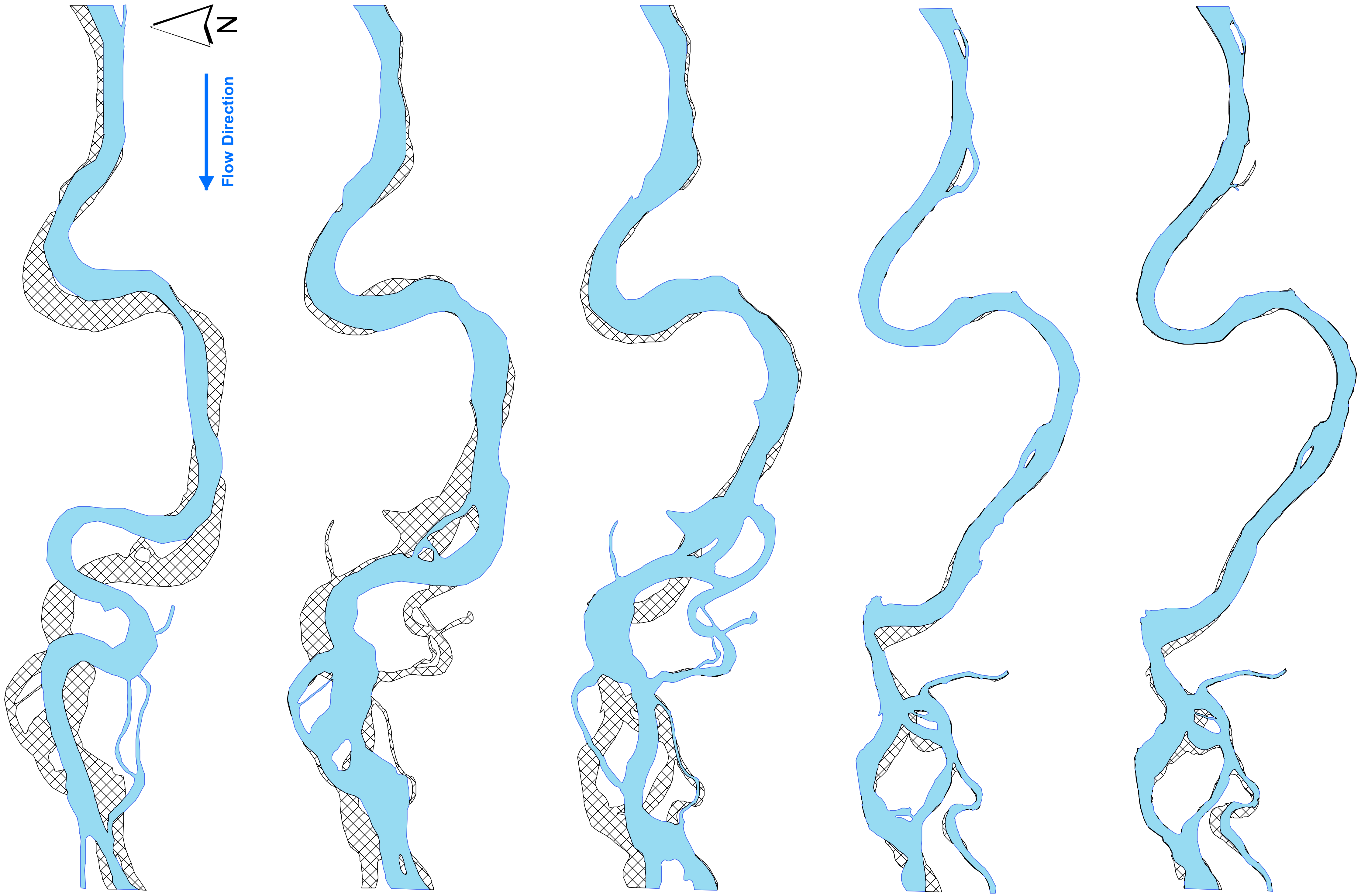
Cockreham Island Alternative Assessment

Hamilton to Lyman: Historical Channel Shifting

Scale - 1:48,000 — 1 inch equals 4,000 feet

0 — 2,000 — 4,000 — 8,000 Feet

WA State Plane, Zone North	horz. datum: NAD 27	horz. units: feet
northwest hydraulic consultants	project no. 21617	June 30, 2008



1886 to 1911

Total Erosion = 26,980,509 sq ft
1911 Channel Length = 40,284 ft
Annual Rate = 26.8 ft/yr

1911 to 1937

Total Erosion = 17,072,635 sq ft
1937 Channel Length = 41,161 ft
Annual Rate = 16.0 ft/yr

1937 to 1994

Total Erosion = 12,877,584 sq ft
1994 Channel Length = 42,486 ft
Annual Rate = 5.3 ft/yr

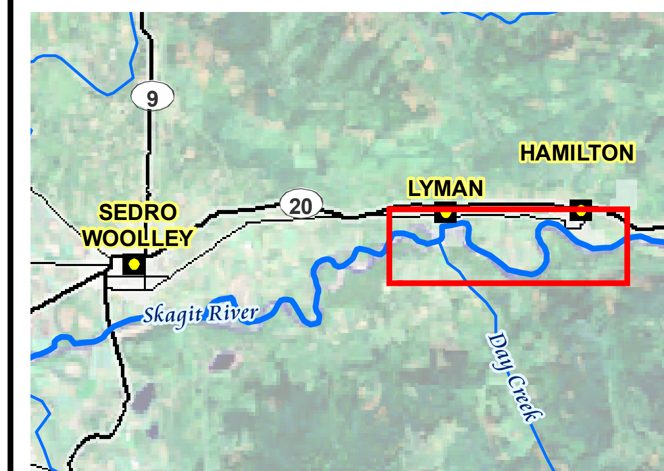
1994 to 2001

Total Erosion = 3,499,918 sq ft
2001 Channel Length = 42,083 ft
Annual Rate = 11.9 ft/yr

2001 to 2006

Total Erosion = 3,750,558 sq ft
2006 Channel Length = 41,992 ft
Annual Rate = 17.9 ft/yr

REFERENCE MAP



LEGEND

- Erosion
- Channel
- Flow Direction

Data Sources:
ESRI Color Satellite Imagery, 2005.
ESRI StreetMap USA Roads, Cities, Counties, and Streams, 2005.

Figure 3 - Hamilton to Lyman: Historical Channel Shifting

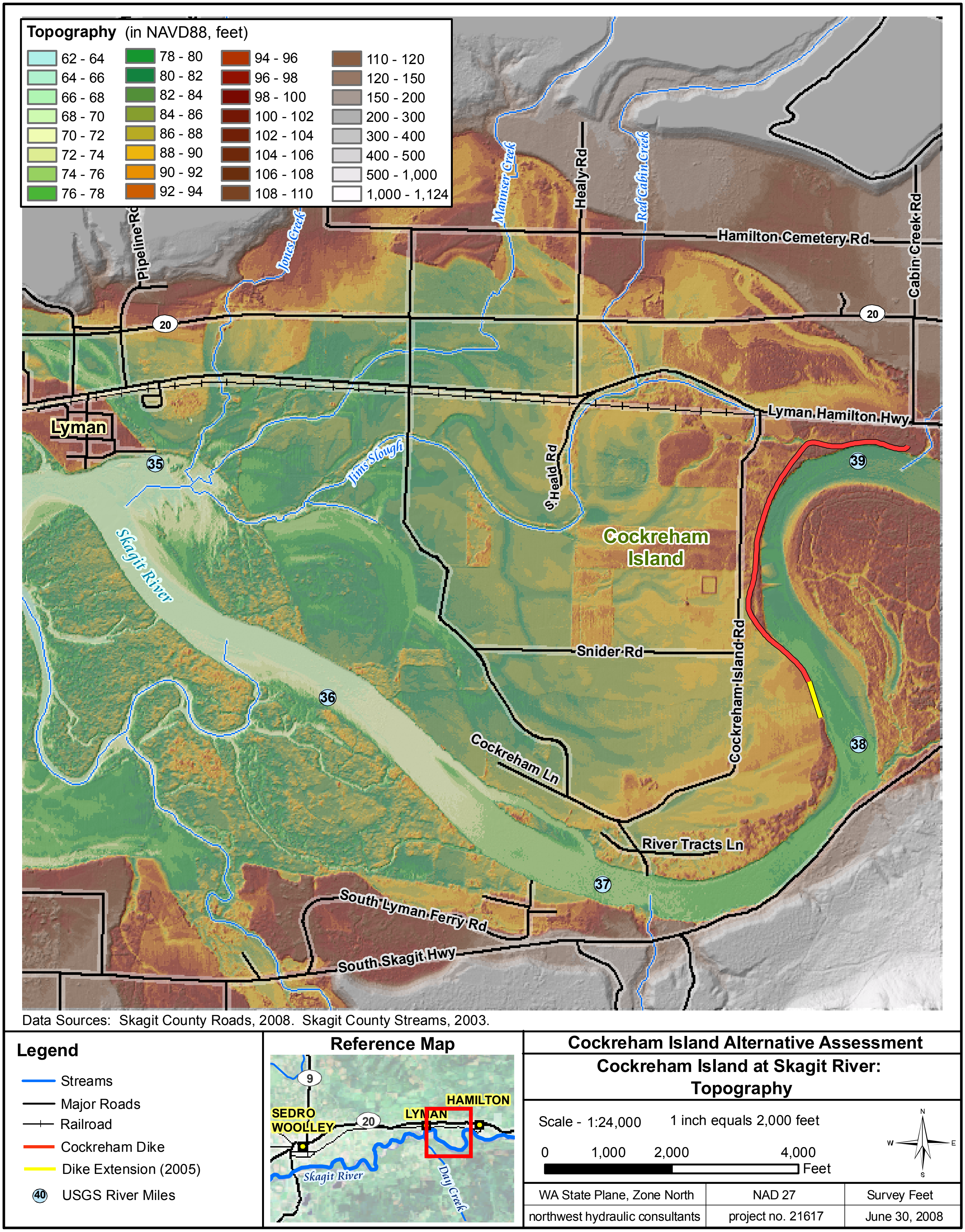


Figure 4 - Cockreham Island at Skagit River: Topography

of coarse sediment on the point bar – essentially point bar growth had to "catch up" with the concave bank erosion.

Since 1937, the changes in the Hamilton to South Skagit Highway subreach have been minor. They include continued expansion of the RM 39 bend to the limit of the Cockreham training dike and narrowing through the section where the Skagit abuts the South Skagit Highway.

South Skagit Highway to Lyman Subreach (RM 37 to 34.5)

Since 1886, the Skagit River has shifted considerably between the South Skagit Highway and Lyman (Figure 2). In 1886, this subreach included two meanders between the Skagit Highway and Lyman. Meander wavelengths were about 4,500 feet, amplitudes were about 4,000 feet, and radii of curvature to width ratios were around 2 (Figure 3). By 1911, the Skagit River had partly abandoned the second meander loop and re-occupied an old flood channel to the south of Lyman. The upstream loop was less altered by the floods between 1886 and 1911, although it migrated west rapidly. The 1937 air photos show an area of complex channel pattern, including flood channels along the path of the 1886 channel and extensive disturbance on the left (south) side of the new channel where the main channel once flowed. This is now part of the habitat complex at the mouth of Day Creek (Figure 1).

Since 1937, the most significant changes to the Skagit River have occurred in the vicinity of Lyman where the right bank just upstream of town has migrated about 1,300 feet (20 feet per year) to the west so that it now directs the main flow of the Skagit River directly at Lyman (Figure 3). From 1994 to 2006, changes to the Skagit River have mostly occurred just upstream and downstream of Lyman (Figure 3).

Lyman is built on a remnant floodplain deposit that now sits above even extreme flood level in the Skagit River. The bank in front of town has been stable for a long time – at least since 1937 – even though considerable channel shifting has occurred near of town. The current stability is understandable given the substantial revetment that Lyman has constructed along the waterfront. It is not known if this revetment has been in place since the late 1930s or if some other feature contributed to the earlier stability at this bend.

The 2006 alignment of the Skagit River is about the worst possible one for Lyman, as the main flow strikes the revetment at nearly a right angle. The historical changes on the bar upstream of Lyman suggest that the main flow will eventually be directed to the west of Lyman towards the entrance of an old flood channel. The old flood channel can be expected to take more flow as this occurs and has the potential to become the main channel and thus migrate north and west at some future date.

Bedload Transport Calculations from Bend Migration

The migration of the RM 39 bend provides an opportunity to estimate historical bedload transport rates before the Cockreham training dike was built. The technique assumes that where a bend is rapidly migrating, bedload from the upstream reach is mostly deposited on the point bar and the bedload carried to the downstream reach is then eroded from the concave bank (see Neill 1971; 1983). Hence, erosion and deposition roughly balance and there is a complete exchange of bedload material. The calculated load is a minimum or lower bound estimate, since some bedload will pass through the bend without "exchanging" or depositing.

Bedload material transport was calculated from the area of erosion that occurred on the concave bank, the average eroded depth of the gravel deposit, and a density of 1.35 tons/yd^3 (Table 2). The depth of gravel eroded was estimated from cross sections surveyed in 1975 for a FEMA Flood Insurance Study. At the bend apex, the island elevation is about 22 feet above the river thalweg elevation. Soil depth is estimated as 6 feet, based on the elevation of gravel exposed on the point bar on the inside bend, leaving a depth of eroded gravel of 16 feet. This bank height is about the same as those shown on the 1911 surveys (USACE 1911). Note that the estimates in Table 2 are consistent with those calculated as a percentage of suspended load in Chapter 2.

Table 2: Minimum Bedload Transport Estimates from Channel Morphology

Years	Concave Bank Erosion (yd^2)	Point Bar Deposition (yd^2)	Average Annual Bedload Transport (tons/year) [1]
1886 to 1911	677,000	357,000	195,000
1911 to 1937	178,000	101,000	49,000
1937 to 1994 [1]	198,000	460,000	79,000
1886 to 1994 [1]	*1,053,000*	-	*110,000*

1. In calculating average transport we assumed that all the channel shifting occurred before 1955, the assumed date when the Cockreham training dike was in place.

Of particular interest is the decline of bedload transport over time. The minimum annual bedload transport between 1886 and 1911 was nearly 200,000 tons, falling to 50,000 tons between 1911 and 1937. As mentioned above, the estimate from 1911 to 1937 may be too low; however, it is likely still considerably less than from 1886 to 1911. The historical pattern then is of a very large volume of coarse sediment entering the Cockreham Island Reach before 1911; followed by below average coarse sediment transport into the reach from 1911 and 1937. This pattern is consistent with the downstream shifting of the sites where channel erosion is concentrated described earlier (Figure 3). This pattern suggests that the large volume of sediment delivered from 1886 to 1911 gradually worked its way through the Cockreham Island reach. The upper part of this reach has become more stable than in the past due to the reduced supply of coarse sediment after 1911. The reduction has occurred because of natural fluctuations in erosion in the upper watershed, recovery from forest harvesting and, more recently, trapping in reservoirs.

Table 2 also shows that the growth of the point bar deposit lagged erosion until after the Cockreham training dike was constructed. Continued growth of the point bar is now narrowing the channel through the bend. **nhc** (2007) points out that, through the dike section, the Skagit River is deepening along the toe of the dike, which helps maintain a roughly constant bankfull cross sectional area despite the narrowing. However, the channel narrowing, sediment deposition, and raised upstream water levels (**nhc** 2007) may exacerbate the risk of an avulsion across the neck of the bend, along the flood channel that is now occupied by Cumberland Creek.

Channel Aggradation

The documentary evidence of changes in historical bed elevations of the Skagit River near Cockreham Island is discussed in **nhc** (2007). R2 Resource Consultants (2004) identified a rise in bed levels downstream of Sedro Wooley of 1.5 feet since the mid-1960s and they also noted channel shortening, which they interpreted as consistent with aggradation along the reach towards Cockreham Island. Comparison of two cross sections near Cockreham Island where surveys were repeated in 1975 and 1999 (Pentec 2000) showed the pattern discussed earlier – narrowing from point bar growth and deepening along the outside of bends. They showed no change in bed levels at one and a modest rise at the other. Based on the above, bed levels may be rising in the vicinity of Cockreham Island, but slowly.

Summary and Projection of Skagit River Behavior

Inspection of historical maps and air photos show that the Skagit River through the Cockreham Island Reach was much less stable from 1886 to about 1937 than it has been since then. A number of factors have contributed to this pattern. First, there was a series of four exceptionally large floods between 1898 and 1922; floods since then have not approached their magnitudes. These floods may have occurred when harvesting of floodplain forests and removal of logjams along the Cockreham Reach had reduced bank strengths. Second, it appears that bedload transport into the reach peaked between 1886 and 1911 and then declined steeply for the next few decades; trapping in upstream reservoirs now significantly lowers overall transport to the reach.

The large influx of bedload into the Cockreham Island reach between 1886 and 1911 resulted in bank erosion and channel shifting that progressed downstream over time as this material was transported through the reach. The reduced bedload transport into the reach since then has contributed to maintaining a relatively stable pattern. Of course, part of the stability is a result of construction of the Cockreham Dike, which prevents migration of the RM 39 bend (and has also caused bedload deposition on the point bar and channel narrowing) and the trapping of the RM 37.5 bend against the South Skagit Highway/south wall of the Skagit Valley. This second bend is also narrowing from point bar deposition.

Based on the above analyses, we have assumed that future channel behavior will be similar to that of the past fifty years or so. Bank erosion and bend migration are expected to continue at low to moderate rates, with a low potential for channel avulsion, chute cutoffs or other channel instabilities as a result of the lack of tight bends and the current low coarse sediment supply. Two sites are exceptions. Continued point bar growth and channel narrowing opposite the Cockreham training dike and South Skagit Highway leave these two bends vulnerable to chute or neck cutoffs. The more likely site for a neck cutoff or avulsion is through the flood channel now partly occupied by Cumberland Creek that lies at the back of the neck of land opposite the Cockreham Dike. Water surface gradients across the neck are at least 50% higher than the reach average because of the much shorter path (interpreted from the USACE working floodplain maps).

If the channel at the Cockreham training dike continues to narrow and upstream water levels continue to rise because of the presence of the dike and the channel narrowing (see **nhc** 2007), this will increase the likelihood of a neck cutoff at Cumberland Creek. We have not tried to evaluate the evolution of the bend in detail, but the time frame for a cutoff is likely decades rather than years. The consequences of a cutoff here are included in the discussion of alternatives in the next section of the report.

4. COCKREHAM ISLAND ALTERNATIVES

GeoEngineers (2007) provided an initial analysis and screening of alternatives for Cockreham Island. Based on their study and subsequent analyses, the County and their partners are considering the first three alternatives summarized below. We have added a fourth alternative based on discussions with the County, as summarized below:

- Alternative 1: Maintain Cockreham Dike but remove the 600-ft long emergency dike extension constructed in 2005.
- Alternative 2: Remove part of original dike, all of the emergency dike, construct a new Skagit River channel across Cockreham Island, plug the existing Skagit River channel downstream from the new channel inlet, and add habitat features.
- Alternative 3: Maintain Cockreham Dike, remove the emergency dike, but provide an inlet structure to allow controlled flows into Jim's Slough.
- Alternative 4: Abandon the Cockreham Dike and protect the Lyman-Hamilton Highway.

The following sections discuss the potential response of the Skagit River to the alternatives, the implications for the County for maintenance or repairs, potential upgrades or capital works, and the studies that might be required for design. When this report was prepared, it was not known if the buy-out of most or all of the private properties on Cockreham Island would proceed or not. If the buy-out does not proceed, some of the alternatives may not be feasible.

Alternative 1: Maintain Training Dike, Remove Emergency Extension

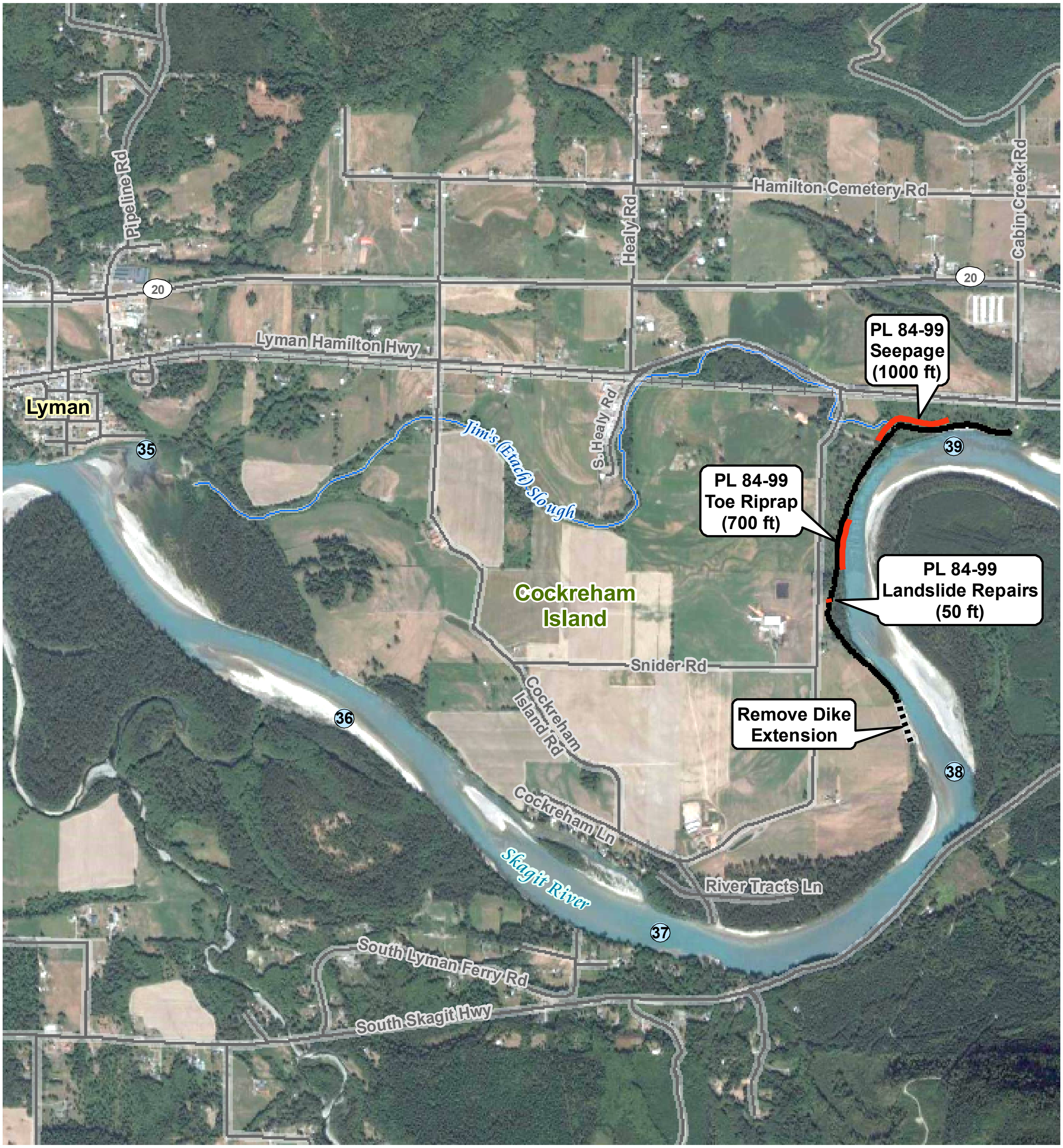
Description of Alternative

Figure 5 shows Alternative 1, consisting of removing the 600 feet of rock placed at the downstream end of the Cockreham training dike in 2005 and completing the PL84-99 repairs to the upstream half of the training dike (in channel toe protection, seepage berm, and treatment of landward slope erosion from water piping through the levee; USACE 2007). This alternative represents returning the training dike to the conditions that existed in 2004 and 2005 resulting in the flooding and erosion conditions that existed at that time.

Projected Response of the Skagit River

The best prediction of the response of the Skagit River to Alternative 1 is based on the flooding observed during the October 2003 and earlier floods. With removal of the rock protection, we would anticipate that the bank would overtop every five years or so. Flows across Cockreham Island would essentially follow the course they did in 2003. Flood photos taken by the Corps of Engineers on October 22, 2003 and the topographic map in Figure 4 indicate that overbank flows will pool in the low area to the east of Cockreham Island Road, flow over the road and roughly southwest through an old swale to the junction of Snider Road and Cockreham Island Road. From here the water will flow into an old meander bend that was part of the 1886 channel.

The right (west) bank of the Skagit River at the site of the dike extension has been mostly stable since 1886, although some very minor retreat has occurred since 1994 (Figure 2). Removal of the emergency extension is not expected to increase rates of bank erosion here.

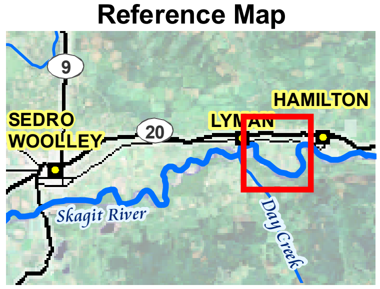


Data Sources: Google Earth Imagery, 2008. Skagit County Roads, 2008. Skagit County Streams, 2003.

Legend

- Major Roads
- Railroad
- Cockreham Dike
- Dike Extension (2005)
- PL 84-99 Repairs
- (40) USGS River Miles

Reference Map



Cockreham Island Alternative Assessment

Alternative 1: Maintain Original Dike, Remove Emergency Extension

Scale - 1:24,000 1 inch = 2,000 feet

0 1,000 2,000 4,000 Feet

N S E W

WA State Plane, Zone North	NAD 27	Survey Feet
northwest hydraulic consultants	project no. 21617	July 15, 2008

Figure 5 - Alternative 1: Maintain Training Dike, Remove Emergency Extension

The main uncertainty seems to be whether or not the overbank flows will erode a channel across the Island. The County indicated that during the 2003 flood, erosion was mostly confined to the area near the river bank, where several deep scour holes formed, and at Cockreham Island Road, where flows overtopped the road and eroded the downstream side of the roadbed. No erosion was reported further downstream, possibly as a result of back flooding from the Skagit River. Based on these observations, we anticipate continued soil erosion in the fields between the river and Cockreham Island Road during moderate sized floods. However, the depth of erosion or scour will be limited by coarse alluvium underlying the soils. Cockreham Road and possibly Snider Road will continue to see damage, unless rock is placed on scour prone areas of the road bed. Downstream of the road the potential for significant damage is limited due to backwater.

In the longer term, over a period of decades, a shallow flood channel might form into the soils, if the erosion is not repaired, but we would expect it to only degrade or incise to where its bed contacts the underlying gravels. Note that if a neck cutoff occurs at the upstream bend through Cumberland Creek flood channel, a new channel could develop rapidly across Cockreham Island through one of the swale areas south of Snider Road.

Consequences for Maintenance and Repair

The implications of removing the dike extension are expected to be:

- Increased frequency of erosion of the fields between the river and Cockreham Island Road.
- Damage to Cockreham Island Road and possibly Snider Road from overbank flows.
- Erosion of cultivated soils and possible damage to year-round crops (raspberries etc.).
- Continued maintenance of the Cockreham Dike and the revetment.
- Maintaining increased flood levels in Hamilton (see **nhc** 2007) which increases the likelihood of avulsion along the Cumberland Creek flood channel.
- Continued maintenance of riprap revetment along the South Skagit Highway. The overbank flows across Cockreham Island will not carry much of the total flow and consequently will only slightly reduce velocities and stresses through the bend. As discussed earlier, continued bar growth, channel narrowing and deepening along the toe of the bank along the Highway will more than compensate for the slightly reduced flows and are likely to increase the damage potential and maintenance costs here over the next few decades.

The County may wish to consider the following actions to mitigate some of these impacts:

- Reduce or prevent scour of the fields between the river and Cockreham Island Road by covering or burying quarry spalls or small rock in the scour prone areas.
- Install a riparian buffer of trees in the field between the river and Cockreham Island Road to reduce overbank velocities and potential erosion.
- Cover vulnerable areas along Cockreham Island Road and Snider Road with rock to prevent erosion.

- Examine and possibly upgrade the erosion protection along the Cockreham Island Dike and the South Skagit Highway.

Recommendations for Further Studies

Alternative 1 returns the Cockreham training dike to the conditions of 2004 and 2005 and the County is familiar with the flooding and erosion that is expected to occur. Suggested future studies for this alternative include the following:

1. Given the importance of maintaining the Cockreham Dike and the revetment along the South Skagit Highway we recommend a detailed review of cross section surveys through both bends, evaluation of the existing dike and revetment relative to Corps standards for such structures, and preparation of concept drawings and costs to upgrade these structures where required.
2. Development of concepts or designs to prevent or reduce erosion in the field between the river and Cockreham Island Road and at the road itself.

Alternative 2: Partial Removal of Training Dike; New Channel Across Island

Description of Alternative

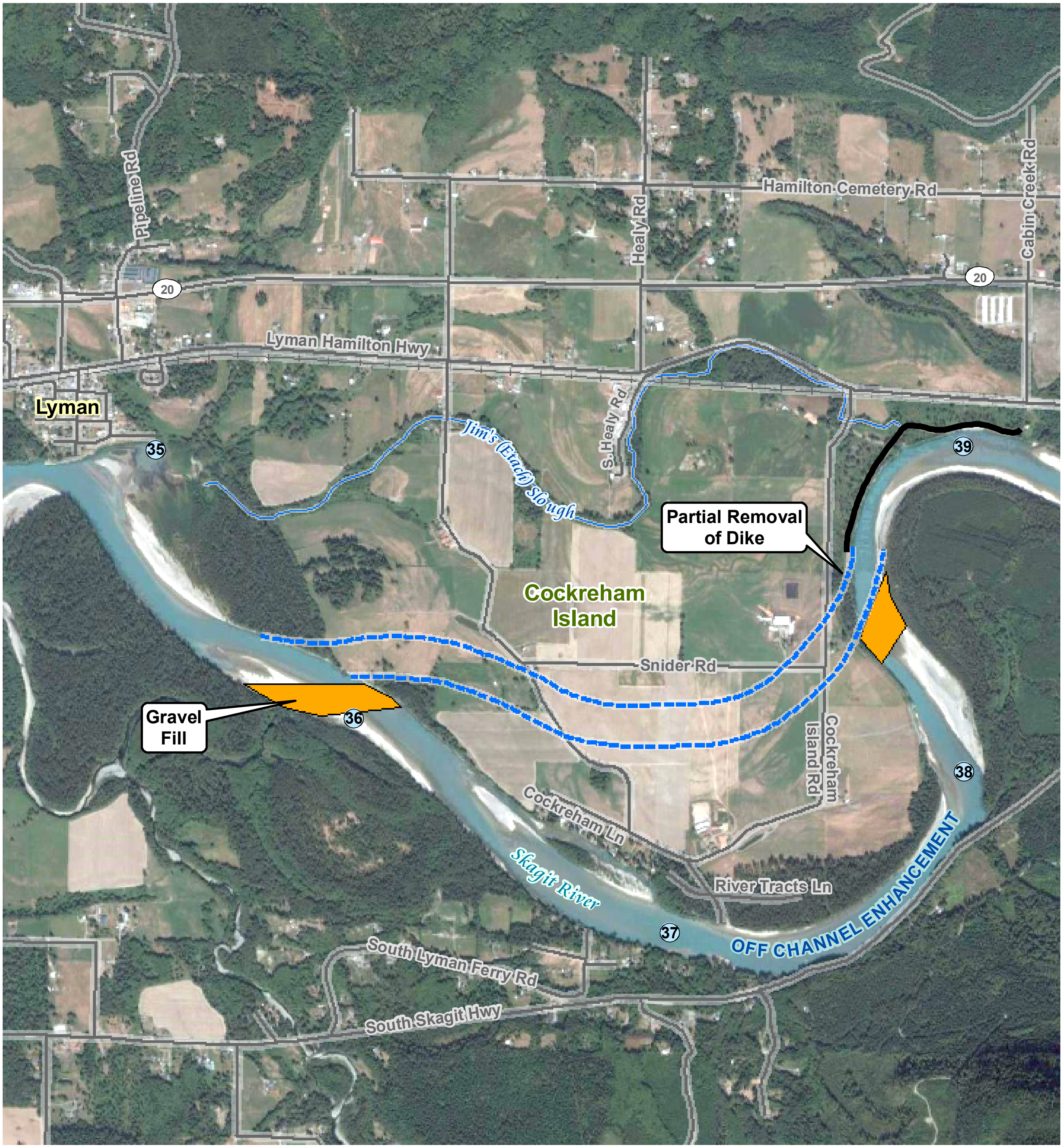
Figure 6 shows Alternative 2, which is based on the concept drawings in the Level 1 Information Feasibility Study Proposal for the "Cockreham Island Enhancement Study" prepared by the County and their partners (May 2007). While not described in detail in the proposal, the main elements of this alternative appear to be:

- Remove the lower 2,000 feet of the Cockreham training dike, presumably including the 600 foot extension built in 2005.
- "Deflect" or "disrupt" the existing flow to encourage a new main channel to form across Cockreham Island (Figure 6). Initial actions might be small structures in the river or a pilot channel across the Island. If unsuccessful, more substantial structures to divert the flow might be required.
- Once diverted, place gravel fills to separate the old main channel from the new channel and create off-channel habitat.
- Habitat enhancement in the slough or pond created along the old main channel.

Projected Response of the Skagit River

Alternative 2 proposes significant modifications to the Skagit River near Cockreham Island that are likely to have both short and long-term consequences. The removal of the lower section of the training dike will still leave the upper 4,000 feet or so in place. As a result, coarse sediment will continue to accumulate on the opposite point bar and the bed of the channel along the training dike will continue to degrade. This is likely to result in continued repairs.

Preliminary hydraulic modeling of removing the lower 3,000 ft of the Cockreham dike (more than proposed in this alternative) showed that water levels in Hamilton were reduced from 0.7 to 1.0 ft for a flow of 160,000 cfs (1995 flood). A slightly smaller reduction would be expected with this alternative. However, the lower flood levels will benefit Hamilton and will also reduce the likelihood of an avulsion through the Cumberland Creek flood channel.

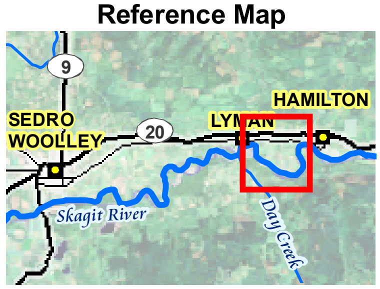


Data Sources: Google Earth Imagery, 2008. Skagit County Roads, 2008. Skagit County Streams, 2003.

Legend

- Major Roads
- Railroad
- Cockreham Dike
- New Channel
- Gravel Fill
- (40) USGS River Miles

Reference Map



Cockreham Island Alternative Assessment

Alternative 2: Partial Removal of Dike, New Channel Across Island

Scale - 1:24,000 1 inch = 2,000 feet

0 1,000 2,000 4,000 Feet

N E S W

WA State Plane, Zone North	NAD 27	Survey Feet
northwest hydraulic consultants	project no. 21617	July 15, 2008

Figure 6 - Alternative 2: Partial Removal of Training Dike, New Channel Across Island

It is difficult to comment on the plan to create a new channel across Cockreham Island, given that it is at a very early stage of development. However, there are several important points to consider. First, as discussed for the previous alternative, simply removing the dike may not result in the Skagit River avulsing across Cockreham Island. Even if a pilot channel is constructed; the bend is fairly open and gradients across the island are not much steeper than in the main channel. If this occurs, the formation of the new channel across the Island would require a substantial deflection structure in the existing main channel to divert the main flow across Cockreham Island. The design of such a structure will be difficult, it will be very expensive to construct, and it will require significant long-term maintenance.

Second, if a new channel is eroded across Cockreham Island considerable channel adjustments will occur where the eroded material is deposited in the Skagit River. The dimensions of the new channel are not exactly known, but a reasonable assumption is that it will average about 800 feet wide, 12 feet deep, and be about 7,000 feet long. On this basis, over 1 million yd^3 (1.4 million tons) of gravel will be eroded which will deposit downstream towards Lyman and a similar volume of fine grained soil will be eroded and carried down the Skagit River in suspension, some of which will deposit and some of which will be carried to Puget Sound. The gravel eroded from the new channel represents over 10 years of average bedload transport and its introduction into the Skagit River will result in significant channel instability near Day Creek, Lyman, and further downstream. This instability will progress downstream over a period of decades, as demonstrated by the historical behavior near Cockreham Island. Given the unpredictable and potentially severe nature of these adjustments, complete excavation of the new channel and offsite disposal before diversion of flow across Cockreham Island should be considered.

Third, it will be important to consider local slope changes during design. The proposed new channel across Cockreham Island is about 40% shorter than the existing channel, and thus it will have a considerably steeper slope. Steep cutoff channels like this, often result in bed lowering upstream from the cutoff, followed by deposition of the coarse material within the cutoff and downstream. Bed lowering upstream of the cutoff could undermine the toe of the existing revetment along the remaining 4000 feet of the Cockreham training dike and possibly extend upstream towards Hamilton and affect bank protection there (if any exists). The deposition of the eroded material near Lyman will in turn will cause channel instability there. Also, if the land bordering the new channel is privately owned, bank protection works may be required to prevent bend development and migration. Countermeasures and repairs are likely to be costly.

Fourth, like the other abandoned channels along the Skagit River, the old main channel will fill with sediment and eventually lose its pond function, which may reduce the apparent habitat benefits of this alternative. How long this will take is not known, but an estimate may be prepared from examination of the potential inflows and the concentration and grain sizes of the suspended sediment carried by the Skagit River.

Consequences for Maintenance and Repair

Implementation of Alternative 2 might have significant implications for the County, including the following:

- Removal of part of the Cockreham training dike, combined with bed incision or degradation, will lower flood levels in Hamilton. This has the advantage of decreasing flood damages in Hamilton (see **nhc** 2007) and reducing the likelihood of an avulsion along the Cumberland Creek flood channel.

- This alternative requires that the upper section of the Cockreham training dike be maintained for the alternative to function and to protect the investment in habitat enhancement and instream works. Given the adjustments to the Skagit River anticipated after construction, we expect that the revetment on the training dike may need to be upgraded and that expenditures for maintenance will rise for a number of years.
- As discussed, maintaining the upper part of the Cockreham Dike will eventually result in continued deposition on the point bar opposite, channel narrowing, and higher upstream flood levels. These conditions increase the likelihood of an avulsion through the Cumberland Creek flood channel over the long-term.
- The gravel barriers between the new and the old main channel may require reinforcement to prevent damage from incident and from overtopping flows. Such protection will be costly to build and will require maintenance.
- Erosion on the Island and upstream (depending on how the project is implemented) might result in deposition of large quantities of coarse sediment and increased suspended sediment loads. The coarse sediment would result in channel instability and potential flood and erosion impacts near Day Creek, Lyman and downstream.
- The County will benefit from reduced maintenance if the main flow is moved away from the South Skagit Highway. In the long-term, if the river cuts through the Cumberland Creek flood channel, it may again flow along the South Skagit Highway which may require countermeasures to protect the road.

Given the uncertainties about how Alternative 2 might be implemented, we have not discussed specific mitigation measures for the County. However, as noted earlier, we recommend complete excavation of the new channel across Cockreham Island to avoid downstream impacts. Also, the studies recommended in the following section may result in specific measures.

Recommendations for Further Studies

Suggested future studies for this alternative include the following:

1. A two-dimensional hydraulic model would help to better understand the potential consequences of dike removal and construction of a pilot channel (or complete excavation the new cutoff channel).
2. As part of assessing the benefits and impacts of this alternative, it will be necessary to predict the response of the Skagit River near Lyman and further downstream to the introduction of the eroded gravel. Prediction of future channel response and adjustment in response to coarse sediment deposition and transport is difficult, thus the level of confidence in the results may be low.
3. As noted above, it will be necessary to maintain the Cockreham Dike to assure the functioning of this alternative. We recommend a detailed review of cross section surveys through the bend, evaluation of the existing dike and revetment relative to Corps or other standards for such structures, and preparation of concept drawings and costs to upgrade

this structure. If it is determined that bed incision may extend upstream to Hamilton, the potential impacts will need to be identified and remedies developed.

4. It is likely that the old main channel will eventually fill with sediment. We recommend studies to determine the likely rate of infill and evaluate the benefits of spending funds to enhance habitat within the channel.
5. A detailed examination should be conducted to try to predict the likelihood of a channel cutoff forming through Cumberland Creek.
6. A detailed design study would be required to develop concepts to deflect the flow into the constructed cutoff channel.

Alternative 3: Jim's (sometimes called Etach) Slough Flow Split

Description of Alternative

Figure 7 shows Alternative 3, which is based on the concept drawings and text included in the "Cockreham Island Enhancement Study" proposal prepared by the County and its partners in May 2007. While not fleshed out in the proposal, the main element of this alternative is an opening through the Cockreham Dike that allows water into Jim's Slough. Inspection of maps and air photos suggest that the opening would be near the bend apex, where Jim's Slough is closest to the Skagit River. The connection would also require adding a culvert at Cockreham Island Road and possibly upgrading some of the other road crossings, depending on the flows that are planned to be diverted.

The general nature of the intake and the flow to be diverted to the slough are not known but it is likely that flow will be diverted throughout the year, requiring either a deep slot or a low intake. The slot is generally preferred, as it allows juvenile egress.

Projected Response of the Skagit River

The successful functioning of Alternative 3 depends on maintaining the upper part of the Cockreham training dike near its existing alignment. As discussed earlier, leaving the training dike in place will not reduce flood levels in Hamilton and will maintain the conditions that may result in a neck cutoff through the flood channel occupied by Cumberland Creek. Such a cutoff would move the channel away and disconnect the river from Jim Slough. The 2005 dike extension would be removed as part of this alternative. As an additional option, a portion of the downstream section of the Cockreham Dike could be removed. This would reduce upstream water levels and lower the likelihood of an avulsion.

Consequences for Maintenance and Repair

Consequences for the County of implementing this alternative include:

- This alternative requires that the upper section of the Cockreham Dike be maintained in place for the alternative to function and to protect the investment in the intake and instream habitat. This alternative will not result in direct impacts on the Dike but the continued narrowing and past erosion of the Dike suggest that it would be prudent to upgrade the existing revetment.

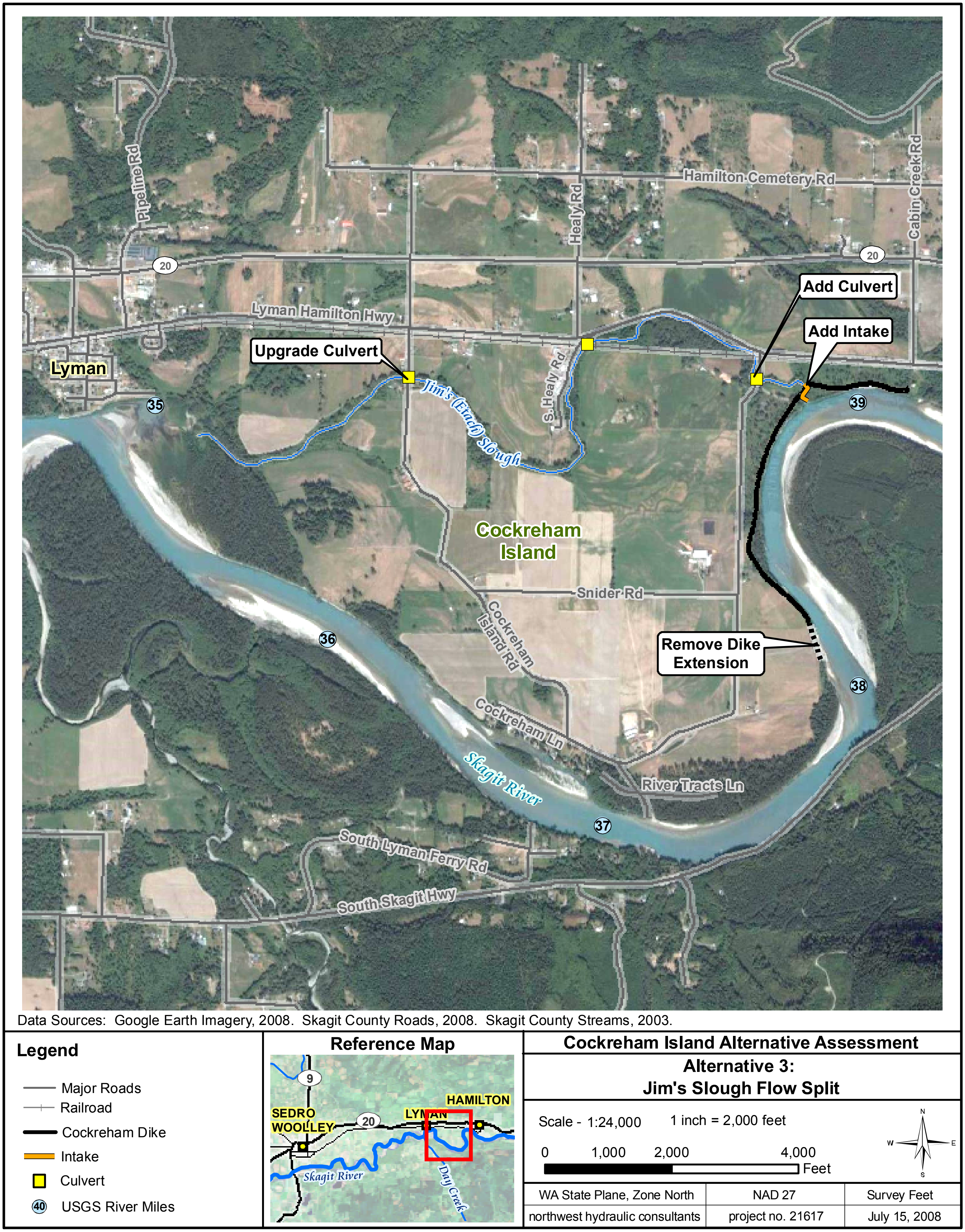


Figure 7 - Alternative 3: Jim's Slough (Sometimes called 'Etach') Flow Split

- Given that Jim's Slough crosses the Lyman-Hamilton Highway, the County should ensure that the flows diverted into the slough do not alter the frequency of flooding of this roadway or of other nearby County or State Roads. Such concerns are likely to affect the design of the intake and may require alterations or upgrades to the Slough and other road crossings to prevent increased flooding.
- The inlet structure will require annual inspection and maintenance.
- Sediment will be ingested at the intake and may deposit within the slough resulting in flooding or damage to habitat. Design and maintenance of a sediment management program will be required as part of Alternative 3.
- Continued maintenance of the riprap revetment along the South Skagit Highway. The flows diverted to Jim's Slough will be a very small part of the total flow and will not reduce velocities and stresses through the RM 37.5 bend.

This alternative also has the same issues as Alternative 1 regarding removal of the 2005 training dike extension. Please refer to the earlier section for details.

Recommendations for Further Studies

The future studies for this alternative include those suggested for Alternative 1 (removal of emergency dike). Other potential studies for this alternative include:

1. Detailed design of the inlet structure, new culvert crossings and possibly a sediment collection/maintenance area to evaluate potential flooding along Jim's Slough.

2. Once Jim's Slough is open to the Skagit River it will begin to ingest suspended sediment. Experience with other similar projects suggests that once ingested, suspended sediments are likely to deposit along the Slough due to reduced velocities. Consequently, sediment management is an important component of the opening design and we recommend incorporating sediment analysis in the intake design and considering management options such as sediment traps, seasonal closure of the intake, etc.

3. As with Alternative 1, given the importance of maintaining the Cockreham Dike and the revetment along the South Skagit Highway we recommend a detailed review of cross section surveys through both bends, evaluation of the existing dike and revetment relative to Corps standards for such structures, and preparation of concept drawings and costs to upgrade these structures.

Alternative 4: Abandon Cockreham Training Dike, Protect Lyman-Hamilton Highway

Description of Alternative

The three alternatives discussed above all require Skagit County to maintain or upgrade the Cockreham Levee and two of the alternatives require the County to continue to maintain revetment along the South Skagit Highway. Alternative 4, shown in Figure 8, is proposed to reduce these commitments. Under this alternative, the County would abandon the Cockreham training dike and instead concentrate their erosion protection along the line of the Lyman-Hamilton Highway, or possibly State Route 20. While considerable further study would be required to develop this concept, we anticipate that the training dike would either be abandoned "as is" or, more likely, the above ground portion of the dike would be removed to allow flood flows across Cockreham Island. Leaving the existing revetment along the concave bank below the top of bank will slow the rate of bend migration and prevent rapid erosion towards the Lyman-Hamilton Highway. This alternative would require initial capital expenditures along the highway to protect against erosion near the RM 39 bend. Future expenditures would then depend on the evolution of the Skagit River; long-term channel adjustments might reduce maintenance requirements along the South Skagit Highway.

Projected Response of the Skagit River

This alternative has some similarities to the dike removal option discussed by GeoEngineers (2007). It allows flood flows to cross Cockreham Island fairly frequently but it maintains control over bank migration in the RM 39 bend. As with the other alternatives, it is difficult to predict how the Skagit River will evolve and whether or not it will develop a new channel across Cockreham Island. In our view, and for the reasons discussed earlier, it is unlikely that a new channel will develop rapidly across Cockreham Island.

The short-term consequences of this alternative will be to lower of flood levels upstream in Hamilton and reduce the likelihood of an avulsion through the Cumberland Creek flood channel. In the short term, flood channels may develop across Cockreham Island, reducing flows in the main channel, and this may slightly reduce maintenance requirements along the South Skagit Highway.

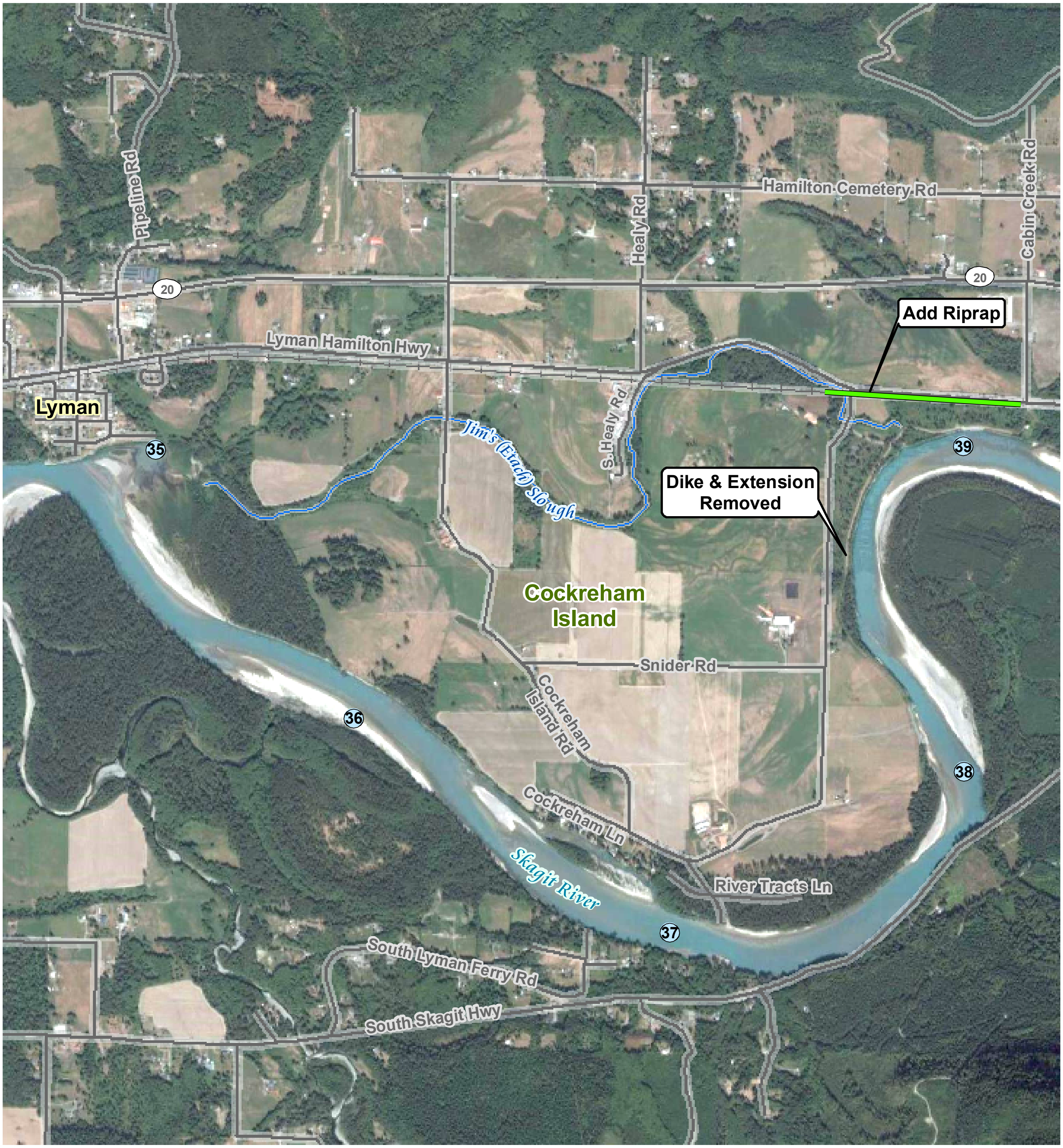
If the dike is removed to local ground elevation, more frequent flooding will occur to the north of Cockreham Island, along the Lyman-Hamilton Highway alignment. Flood flows will enter Jim's (Etach) Slough and installation of a new culvert at Cockreham Island Road and upgrades to other culverts may be needed to manage flows and prevent flooding. Rock protection will be needed along some road segments and it may be necessary to raise some road segments to maintain operation during reasonably frequent floods. It may also be necessary to provide rock protection near Lyman if substantial flows cross Cockreham Island towards the east and north part of the town.

In the long-term, the Skagit River may avulse into a new channel across Cockreham Island. If this occurs, the upstream and downstream responses and recommendations discussed for Alternative 2 should be considered.

Consequences for Maintenance and Repair

The short-term consequences for the County of implementing this alternative include:

- Given an increased frequency of flooding north of the RM 39 bend, the County may need to construct works to pass overbank flows along Jim's Slough and ensure that the frequency of flooding along the Lyman-Hamilton Highway or on other nearby County or State Roads is not altered. Alterations or upgrades to Jim's Slough may be required.

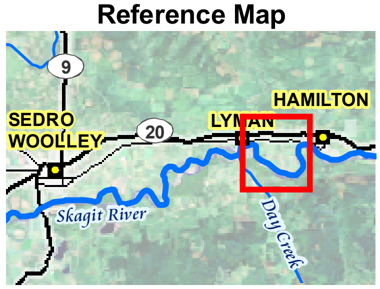


Data Sources: Google Earth Imagery, 2008. Skagit County Roads, 2008. Skagit County Streams, 2003.

Legend

- Major Roads
- Railroad
- Riprap
- 40 USGS River Miles

Reference Map



Cockreham Island Alternative Assessment

Alternative 4:
Abandon Cockreham Dike

Scale - 1:24,000 1 inch = 2,000 feet

0 1,000 2,000 4,000 Feet

N S E W

WA State Plane, Zone North	NAD 27	Survey Feet
northwest hydraulic consultants	project no. 21617	July 15, 2008

Figure 8 - Alternative 4: Abandon Cockreham Training Dike

- Rock protection will be required along the Lyman-Hamilton Highway to protect from greater overbank flows. Over time, increased overbank flows may require additional protective works.
- This alternative would require monitoring by the County to determine the need for counter measures to protect private property on the floodplain and may require extensive works if the Skagit River avulses across Cockreham Island.
- Continued maintenance of the riprap revetment along the South Skagit Highway. The flows diverted across Cockreham Island by the removal of the above-ground portion of the Dike will help reduce maintenance commitments initially. Over the long-term, maintenance may be substantially reduced by diversion of more and more flow across the Island.
- The removal of the above-ground portion of the levee will lower flood levels in Hamilton and reduce the likelihood of avulsion along the Cumberland Creek flood channel.
- Maintenance and repair commitments for the Cockreham Dike will end.

Recommendations for Further Studies

The future studies suggested for this alternative include

1. Consider developing a 2-D hydraulic model of the Cockreham Reach to assess hydraulic conditions across the island if the dike is removed to ground level and help evaluate the potential erosion, flood levels and the needs for repair or erosion protection as far downstream as Lyman.
2. Design any needed alterations to Jim's Slough that reduce potential flooding and provide aquatic habitat. Complete an analysis to determine if sediment management may be required within the slough to maintain aquatic habitat.

As discussed, we consider an avulsion across Cockreham Island in the short-term to be unlikely. However, it may be prudent to undertake the recommended studies for Alternative 2 to help evaluate potential impacts should one occur.

Summary of the Alternatives

Table 3 (following) summarizes the implications for the County for maintenance, repair, upgrades and new structures for flood and erosion control for Alternatives 1 through 4 based on the qualitative evaluations discussed earlier. Alternative 1 returns the training dike to 2004/2005 conditions and represents something close to existing conditions; commitments for maintenance, repair, upgrades and new structures for the other alternatives are then compared to Alternative 1.

Table 3: Summary of Impacts of Cockreham Island Alternatives on County Responsibilities

Alter-native	*Training Dike & Revetment*	*South Skagit Highway*	*New Structures*	*Skagit R. Near Hamilton*	*Skagit R. Near Lyman*	*Lyman-Hamilton Highway*	*Other Private Property*	*Capital Costs*
1	Continued maintenance at current levels	Continued maintenance at current levels	None	Current conditions	No project impacts	No project impacts	None anticipated	Low
2	Increased maintenance; upgrades recommended	Maintenance eliminated to at least medium term	Deflection structures, pilot channel, gravel fills; poss. Diversion works	Lower flood levels and lower avulsion potential	Erosion, deposition and channel instability	Potential for more frequent flooding	Low to Moderate	Very High
3	Continued maintenance; upgrades recommended	Continued maintenance; upgrades recommended	Intake; new culvert; upgrade other culverts	No benefit, avulsion potential	No project impacts	Flooding from flows through Jim's Slough	Poss. along Jim's Slough	Moderate
4	No further maintenance required	reduced maintenance in short-term; possibly greater in long-term	Erosion and flood protection along Highways	Lower flood levels and lower avulsion potential	Short-term none; Long-term uncertain	More frequent flooding from flows across Island	Potential damage from overbank flows	High

Alternatives:

- Alternative 1: Maintain Training Dike, Remove Emergency Extension
- Alternative 2: Partial Removal of Training Dike; New Channel Across Island
- Alternative 3: Jim's (sometimes called Etach) Slough Flow Split
- Alternative 4: Abandon Cockreham Training Dike; Protect Lyman-Hamilton Highway

5. CONCLUSIONS AND RECOMMENDATIONS

The County, in cooperation with other agencies and local landowners, is considering a number of different options or alternatives for Cockreham Island. Skagit County Department of Public Works is reviewing their flood and erosion protection program for the Skagit River near Cockreham Island and also considering the consequences of the different alternatives on their existing structures and on their maintenance responsibilities. Some of the alternatives seem to require buy-out of private lands on the Island to be implemented. If buy-out does not occur, these alternatives may not be feasible.

This report evaluated the maintenance, upgrades or new structures that might be required for flood and erosion protection and identify other obligations or impacts on the County that might result from implementation of four different alternatives. Alternative 1 essentially returned the Cockreham training dike to 2004/2005 conditions and represents a base-line for comparing the other three alternatives. The evaluations are qualitative and are summarized in Table 3 (previous page). We also briefly considered the engineering analyses or studies that might be needed to carry the alternatives through to design and implementation.

In order to evaluate the consequences of the different alternatives proposed for Cockreham Island on the County's flood and erosion control program, it is necessary to predict the future behavior of the Skagit River near Cockreham Island and its potential response to the different alternatives. Our predictions are preliminary and are based on a brief field reconnaissance, discussions with the County, a review of previous studies and existing information, and analysis of historic maps and air photos. Some further studies are also recommended to confirm some of our assumptions.

An important point in our projection of conditions in the Skagit River through the Cockreham Island reach is that continued point bar growth and channel narrowing are anticipated opposite the Cockreham Levee and opposite the South Skagit Highway. In our view, these trends have several consequences. One is increased maintenance expenditures to maintain existing revetment; another is the potential for increased flood levels in Hamilton. As discussed in the text, the bar growth and narrowing opposite the RM 39 bend may eventually result in an avulsion – the most likely path consists of a neck cutoff through the flood channel now partly occupied by Cumberland Creek.

Alternative 1, which removes the emergency extension of the Cockreham training dike, is unlikely to result in an avulsion across Cockreham Island, as interpreted from experience during past floods. The removal of the extension, combined with the PL 84-99 repairs, returns the training dike to the conditions of 2004 and 2005, and the Island is subject to the erosion and flooding risks that were prevalent at that time. These include flooding and erosion of the Island during fairly frequent floods.

Given experience during past floods, it is possible that removal of the lower part of the Cockreham training dike combined with deflection works or a pilot channel – as are currently considered for Alternative 2 – may not divert the Skagit River across Cockreham Island. Should this occur, it will be necessary to construct a substantial structure in the main channel of the

Skagit River in order to divert the flow across Cockreham Island as is proposed for Alternative 2. Our conclusion is based on limited evidence – constructing a two-dimensional hydraulic model that included Cockreham Island might help resolve the likely response to removal of part of the training dike and other “encouragements” to diversion.

In our view, diverting the flow across Cockreham Island and allowing a new channel to erode sediments and deposit them in the Skagit River downstream would result in a long episode of channel instability with the potential for considerable negative consequences in the vicinity of Day River, Lyman and further downstream. We would recommend constructing a channel across Cockreham Island, rather than trying to erode one, to avoid many of these consequences. If Alternative 2 proceeds with the idea of eroding a channel across Cockreham Island, we recommend studies that attempt to predict the downstream response and potential impacts on valued habitat to weigh against habitat potentially created at Cockreham Island.

The three alternatives proposed by the County and their partners all depend on maintaining the Cockreham training dike and, for two alternatives, maintaining revetment along the South Skagit Highway. In fact, the functioning of Alternatives 2 and 3 depends on maintaining the training dike in its current alignment. Given the importance of the training dike to these alternatives, we recommend a review of the condition of the levee and revetment and preparation of conceptual upgrades and costs to be included in the capital cost of these alternatives. These upgrades might also be appropriate along the South Skagit Highway for Alternative 3.

Finally, a fourth alternative for Skagit County would be to abandon the Cockreham Dike and construct a new line of erosion defense along the Lyman-Hamilton Highway or State Route 20. The abandonment would likely consist of removing the above-ground portion of the dike but leave the bank revetment in place. Such an alternative would result in more frequent flooding of the northeastern part of Cockreham Island and, possibly, also of the area towards Lyman, but would help control channel migration rates. Initial capital expenditures would be needed to protect against flooding and erosion around the Lyman-Hamilton Highway and possibly also in other locations. Detailed hydraulic studies would be needed to identify and address such potential impacts.

In the short-term we do not expect the Skagit River to avulse across Cockreham Island under Alternative 4. However, it may in the future and increased flows may commit the County to a program of countermeasures on private property near the Lyman-Hamilton Highway. These flows across Cockreham Island might slightly reduce maintenance requirements along the South Skagit Highway. Longer-term adjustments may substantially reduce them.

6. REFERENCES

Collins, B. and T. Dunne. 1990. Fluvial Geomorphology and River-Gravel Mining: a Guide for Planners, Case Studies Included. California Department of Conservation, Division of Mines and Geology, Special Publication 98. 29 p.

Collins, B. and A. Sheikh. 2002. Methods used to map the historical riverine landscape and habitats of the Skagit River. Report to the Skagit System Cooperative. LaConner, WA. September 12. 46 pp.

Collins, B. and A. Sheikh. 2003. Historical aquatic habitat in river valleys and estuaries of the Nooksack, Skagit, Stillaguamish and Snohomish watersheds. Report to Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. May 1.

Collins, B. 1992. River-Channel Sediment Budget and Gravel Mining, 1962-1991, in the Stillaguamish River, Snohomish County, Washington. Prepared for Long Star Northwest, Seattle, Washington. 41 p.

Dragovich, J., D. McKay, D. Dethier and J. Beget. 2000. Voluminous laharic inundation of the lower Skagit River valley, Washington (abs). Geological Society of America Abstracts with Programs 23(6): A11.

GeoEngineers. 2007. Cockreham Island Buy-Out Feasibility Study: Skagit County, Washington. Report for Skagit County Public Works. May 14.

Kellerhals, R. and M. Church. 1989. The morphology of large rivers: characterization and management. In Dodge, D (ed). Proceedings of the International Large River Symposium. Canadian Special Publications of Fisheries and Aquatic Sciences 106: 31-48.

Mastin, M.C. 2007. Re-evaluation of the 1921 Peak Discharge at Skagit River near Concrete, Washington. United States Geological Survey Scientific Investigations Report 2007-5159. 12 pp.

Neill, C.R. 1971. River Bed Transport Related to Meander Migration Rates. ASCE Journal of the Waterways, Harbors and Coastal Division 97: 783-786.

Neill, C.R. 1983. Bank Erosion Vs Bedload Transport in a Gravel River. Rivers 83. Proceedings of the ASCE Waterway, Port Coastal and Ocean Division. Pp. 204-211.

Northwest hydraulic consultants. 2004. Stillaguamish River North Meander Reconnection Habitat Restoration Project: Alternatives Analysis Report. Snohomish County Surface Water Management. 45 pp.

Northwest hydraulic consultants. 2007. Skagit River Hydrology: Independent Technical Review. Final Report for Skagit County Department of Public Works. 38 pp.

Pentec Environmental Inc. 2000. Cockreham Island Training Levee Conceptual Plan Alternatives Study and Mitigation Plan. Prepared for Skagit County Public Works Department.

R2 Resource Consultants, Inc. 2004. Baker River Hydroelectric Projects (FERC No. 2150): Hydrology and Geomorphology of the Baker and Middle Skagit Rivers. Part 2: Sediment Transport and Channel Response. Puget Sound Energy, Inc. February.

Tabor, R., D. Booth, J. Vance and A. Ford. 2002. Geologic Map of the Sauk River 30- by 60-Minute Quadrangle, Washington. USGS Miscellaneous Investigation Series I-2592.

US Army Corps of Engineers. 1911. Skagit River from Baker River to Sedro Woolley, Washington. 5 Sheets (4,000 feet to the inch). August 24 to September 18.

US Army Corps of Engineers. 2007. Project Information Report: PL 84-99 Flood Repair, Cockreham Island Levee. 2 Sheets. Prepared July 6, 2007 by Tetra Tech of Seattle Washington for the Seattle District.