FINAL REPORT

Ladd Landing Development Bulkhead Facility Coastal Engineering Evaluation

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Section 1: INTRODUCTION

PacRim Coal, LP, is planning to develop the Chuitna coal deposit in the Beluga coal field on the west side of Cook Inlet and requires port facilities for unloading equipment and materials. The current port design concept includes an oblong manmade island with approximate dimensions of 800 ft parallel to shore and 300 ft perpendicular to shore. The island will be separated from shore by a channel of at least 320 ft width, but possibly as much as 570 ft width (at MSL). The purpose of the island is to provide storage and laydown area to support vessels that will dock at a shore-parallel pier connected to the island by a 500-ft long bridge.

Section 2: PROBLEM STATEMENT

Of concern is whether the channel between the island and mainland will support sufficient alongshore flow to avoid excessive sediment deposition, so as to remain useful as a waterway. The coastal engineering evaluation of the design concept requires answers to two questions:

a. How will alongshore flow be affected by the island?
b. How much sediment deposition should be expected within the channel?

Two locations of the island were considered:

a. Seaward side of island at -10 ft (re: MLLW) depth, which results in a channel width ~ 330 ft from bulkhead to shore (MSL)

b. Seaward side of island at -15 ft (re: MLLW) depth, which results in a channel width ~ 570 ft from bulkhead to shore (MSL).

Section 3: SUMMARY & CONCLUSIONS

As described in following sections, flow in the channel between the manmade island and mainland was analyzed with the Manning equation. Although applicable primarily to steady, uniform open channel (i.e. free surface) flows, the Manning equation can be applied also to slowly varying flows such as tidal currents over short periods. Current speeds in the channel were related to flows seaward of the island and found to be about 1 m/s (2 kt) when offshore flows are 2 m/s (4 kt), which occur at mid-tide. At high tide, channel current speeds can be expected to be about 0.3 m/s (0.6 kt), while at low tide about 0.15-0.20 m/s (0.3-0.4 kt).

To address the concern of whether sediment might accumulate in the channel because of the reduced current speeds, the Shields parameter was applied as a criterion to determine the threshold current speeds for incipient motion for the range of sediment sizes likely to occur at the project site. For Configuration A (Appendix A), incipient motion would likely occur for sediments up to 0.1 mm diameter, while for Configuration B (Appendix B), incipient motion would likely occur for sediments up to 0.2 mm diameter.

As no site-specific data on suspended sediment were available, data that were collected recently near Point MacKenzie were assumed to be reasonably similar to what might be found at Ladd Landing. Grain size analysis indicated that 98 percent of the suspended sediments were less than 0.1 mm in size, and 70 percent were less than 0.02 mm. If these TSS data are reasonably similar to what might be found near Ladd Landing, it is reasonable to conclude that accumulation of sediment in the channel is unlikely for both configurations.

Section 4: METHODS

4.1 CHANNEL HYDRAULICS

Flow in the channel will be the result of bifurcation of the main alongshore flow around the island. For both ebb and flood tides, flows will be parallel to the shoreline. On ebb tide the flow will be toward southwest, while on flood the flow will be toward northeast. The Manning equation is used to relate flow speed within the channel to the “free stream” flow speed, where the latter refers to the unobstructed flow offshore of the island.

The Manning equation is an empirical relationship that has been demonstrated to be a reliable tool for estimating flow speeds in steady, uniform flows. Practical applications of the Manning equation are described in nearly every textbook on elementary fluid mechanics and hydraulic engineering (e.g. see Vennard and Street, 1975).

In addition to its application to steady, uniform flows, the Manning equation is reliable when flows are varying only slowly with time, so it can be used in a stepwise fashion for analysis of tidal flows over short periods. The Manning equation relates flow variables in free surface flows as follows:

$$U = (1/n)\, R^{2/3}\, S^{1/2} \qquad (1)$$

In equation (1) U is flow speed, n is Manning’s roughness coefficient, R is hydraulic radius (= flow cross-sectional area A divided by wetted perimeter P), and S is slope of water surface[2].

The Manning equation can be used to relate the variables of flow both within the channel and at some distance from the island:

$$U_i = (1/n_i)\, R_i^{2/3}\, S_i^{1/2} \qquad (2)$$

and

$$U_o = (1/n_o)\, R_o^{2/3}\, S_o^{1/2} \qquad (3)$$

Subscripts *i* and *o* refer, respectively to “inner” (channel) and “outer” (free stream) flows seaward of the island. Assuming that seabed roughness coefficients are equal both within the channel and on the seaward side of the channel and, also, that the water surface slopes are generally the same, equation (2) can be divided by equation (3) to obtain the ratio of flow speeds:

$$U_i / U_o = (R_i / R_o)^{2/3} \qquad (4)$$

In the attached spreadsheets (Appendices A and B) this equation is solved for both island configurations in the sections called “Inner Channel Currents” to find the ratios of flow speeds for three water surface elevations: MHW, MSL, and MLLW.

4.2 SEDIMENTATION

Deposition of sediment within the channel can occur as a result of slowing of the alongshore flow as it moves through the channel. In the “freestream” region of the flow (i.e. where flow is unaffected by the island), the total suspended sediment (TSS) in the water column is maintained at a generally constant concentration because sediment deposited on the seabed is replaced by sediment that is re-suspended by

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[2] Equation (1) is the metric form of the Manning equation. For use with English system of dimensions, the numerator of the term containing the roughness coefficient n is 1.486.

turbulence within the flow. A sediment particle of given size and density may be assumed to remain in suspension as long as the flow speed is greater than that required to cause incipient motion of the particle on the seabed.

Incipient motion of a sediment particle occurs when fluid forces of lift and drag on the particle overcome the weight and inertia of the particle and cause it to be moved in the direction of flow. Once the particle begins to move, fluid turbulence will propel the particle upward into the water column, where the flow speeds are even greater than at the seabed. For particles of similar density (i.e. sand, silt, and clay), the larger (coarser) particles will require greater flow speeds for incipient motion than the smaller particles. Accordingly, the problem of determining whether deposition will occur in the channel becomes determination of the maximum size particle that will remain in suspension with the reduced flow speed.

The Shields parameter is considered to be the best indicator of incipient particle motion, and is defined as follows:

$$\Psi = \tau_b / [\, \gamma \,(S_s - 1)\, d] \qquad (5)$$

In equation (5), Ψ is the Shields parameter, τ_b is the shear stress exerted on the seabed by the fluid flow, γ is the specific weight of the fluid (i.e. seawater), S_s is the specific gravity of the sediment, and d is the nominal diameter of the sediment particle. Experimental evidence indicates that, if $\Psi > 0.03$, it is likely that the sediment is moving and, if $\Psi > 0.1$, it is a virtual certainty that bottom sediments are moving with the flow (Dean & Dalrymple 2002).

Seabed shear stress τ_b can be replaced in equation (5) by its equivalent, $\rho f U^2/8$, in which ρ is fluid density, f is the Darcy-Weisbach friction coefficient, and as before, U is fluid velocity. Making this substitution in equation (5) results in the following:

$$\Psi = (\rho f U^2/8) / [\, \gamma \,(S_s - 1)\, d] \qquad (6)$$

Insertion of the relationship $\gamma = \rho g$ (g = acceleration of gravity = 9.8 m/s^2), $f = 0.02$ (typical of seabed roughness), and $S_s = 2.5$ reduces equation (6) to

$$\Psi = 0.000170\, U^2 / d \qquad (7)$$

Equation (7) is solved in the “Inner Channel Sediment Transport” sections of the attached spreadsheets (Appendices A and B) for the minimum current speeds expected in the channel for a range of sediment particles that can reasonably be expected to occur in the alongshore flow at this location in Upper Cook Inlet.

Section 5: RESULTS

5.1 CURRENTS

Application of the Manning equation to calculate currents within the Inner Channel, relative to the Outer Channel, or "free stream," produced the results summarized in Table 1-1. Outer channel current speeds are representative of near-surface speeds observed by Smith and Khokhlov (2006).

Table 1-1. Summary of Current Speeds

Tide Stage	Outer Channel (m/s)	Inner Channel (m/s)	
		A	B
MHW	0.5	0.31	0.32
MSL	2.0	1.08	1.16
MLLW	0.5	0.14	0.20

As expected, greatest reduction in current speed occurs at MLLW and and all current speed reductions are less with wider channel (B) than with narrower channel (A), although the differences are not substantial, except at MLLW.

5.2 SEDIMENT TRANSPORT

The Shields parameter was computed for both configurations for sediment diameters ranging from 0.005 to 0.200 mm. Results are summarized in Table 2-1 and indicate that for Configuration A, incipient motion would likely occur ($\Psi \geq 0.03$) for sediments up to 0.1 mm diameter in size. For Configuration B, incipient motion would likely occur for sediments up to 0.2 mm diameter. In both cases, as would be expected, the critical condition occurs at MLLW, when water levels are lowest.

Table 2-1. Summary of key sediment transport results

Shields Parameter	Applicable to Sediment Particles ≤ Diam. (mm)	
	A	B
$\Psi \geq 0.03$: sediment movement "likely"	0.10	0.20
$\Psi \geq 0.10$: sediment movement "virtually certain"	0.02	0.07

Lacking any site-specific suspended sediment data, the following conclusions are based on TSS concentrations obtained as part of another study, performed in support of the Knik Arm Crossing Environmental Impact Statement (KLI 2006, 2007). Data cited here were collected at 20% local depth (about 10 m) in mid-channel due south of Point MacKenzie. Water samples were collected to determine total suspended sediment (TSS) concentrations, and samples were analyzed to determine sediment size distributions.

At this location TSS ranged from 800 to 1,000 mg/L in September 2006. Grain size analysis indicated that 98 percent of the suspended sediments were less than 0.1 mm in size, and 70 percent were less than 0.02 mm. If these TSS data are reasonably similar to what might be found near Ladd Landing, it is reasonable to conclude that accumulation of sediment in the channel is unlikely for both configurations.

Section 6: CONCLUSIONS

Assuming that the above-referenced TSS sample is reasonably representative of conditions at proposed site for the Ladd Landing Development Bulkhead Facility, it is concluded that sediment accumulations in the Inner Channel, as a result of lower current speeds there, would be hardly noticeable with Configuration A, and would not occur at all with Configuration B.

Section 7: REFERENCES

Dean, R. G., and R. A. Dalrymple. 2002. Coastal Processes with Engineering Applications, Cambridge University Press, Cambridge, U.K. 475 p.

Kinnetic Laboratories Inc. (KLI). 2006[2]. Settling Velocity Evaluations for Suspended Sediment – Knik Arm, Cook Inlet, Alaska. Oct. 2006. 6 p. + App.

Kinnetic Laboratories Inc. (KLI) 2007[2]. Current and Suspended Sediment Investigation – Knik Arm, Cook Inlet, Alaska. Jan. 2007. 20 p.

Smith, O. P., and A. Khokhlov. 2006. Tidal Current Studies – Ladd Landing Coal Dock. Report to PND Engineers, Inc. 29 Sept. 2006. 22 p. + App.

Vennard, J. K., and R. L. Street.. 1975. Elementary Fluid Mechanics, 5th ed. J. Wiley & Sons, New York, NY. 740 p.

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[2] These reports are included as attachments to Appendix IX, Hydrology and Hydraulic Environment of Knik Arm, which will be posted as a project support document for the Knik Arm Crossing Final Environmental Impact Statement on the Knik Arm Bridge and Toll Authority website, http://www.knikarmbridge.com/

APPENDIX A

LADD LANDING BULKHEAD FACILITY

CONFIGURATION A

LADD LANDING BULKHEAD FACILITY - COASTAL ENGINEERING EVALUATION

Configuration "A"

Inner Channel Currents

Location	Horizontal Distance from MHW (ft)	Elevation re: Sta. Datum (ft)	Elevation re: MSL (ft)	Seabed Slope	Inner Channel Water Surface Width (ft)	Inner Channel Flow Cross-Section (ft^2)	Inner Channel Average Depth (ft)	Depth at Landward Face (ft)	Inner Channel Wetted Perimeter (ft)	Inner Channel Hydraulic Radius (ft)	Seaward Channel Average Depth (ft)	**Current Speed Ratio (inner / outer)**
Symbol					*W*	*A*	*D*		*P*	*R (=A/P)*		***u / U***
MHW	0	26.83	8.5		380	6207	16.3	23.4	404.1	15.4	31.9	**0.61**
				0.170								
MSL	50	18.34	0.0		330	3189	9.7	14.9	344.9	9.2	23.4	**0.54**
				0.075								
MLLW	200	7.16	-11.2		180	333	1.9	3.7	183.7	1.8	12.2	**0.28**
				0.021								
Landward island face	380		-14.9									
				0.021								
Seaward island face	680		-21.2									

Inner Channel Sediment Transport

	Current Speeds (m/s)			**Shields parameter as function of sediment diameter**							
	Outer	**Inner**									
			Sed. (mm)	***0.2***	***0.15***	***0.1***	***0.07***	***0.05***	***0.02***	***0.01***	***0.005***
MHW	0.5	0.31		0.08	0.11	0.16	0.23	0.32	0.80	1.60	3.21
MSL	2	1.08		0.99	1.31	1.97	2.81	3.94	9.85	19.70	39.41
MLLW	0.5	0.14		0.02	0.02	0.03	0.05	0.07	0.17	0.33	0.67

APPENDIX B

LADD LANDING BULKHEAD FACILITY

CONFIGURATION B

LADD LANDING BULKHEAD FACILITY - COASTAL ENGINEERING EVALUATION

Configuration "B"

Inner Channel Currents

Location	Horizontal Distance from MHW (ft)	Elevation re: Sta. Datum (ft)	Elevation re: MSL (ft)	Seabed Slope	Inner Channel Water Surface Width (ft)	Inner Channel Flow Cross-Section (ft^2)	Inner Channel Average Depth (ft)	Depth at Landward Face (ft)	Inner Channel Wetted Perimeter (ft)	Inner Channel Hydraulic Radius (ft)	Seaward Channel Average Depth (ft)	**Current Speed Ratio (inner / outer)**
Symbol					*W*	*A*	*D*		*P*	*R (=A/P)*		***u / U***
MHW	0	26.83	8.5		620	12429	20.0	23.4	644.1	19.3	36.9	**0.65**
				0.170								
MSL	50	18.34	0.0		570	7371	12.9	14.9	584.9	12.6	28.4	**0.58**
				0.075								
MLLW	200	7.16	-11.2		420	1827	4.4	3.7	423.7	4.3	17.2	**0.40**
				0.021								
Landward island face	620		-19.9									
				0.021								
Seaward island face	920		-26.2									

Inner Channel Sediment Transport

	Current Speeds (m/s)			**Shields parameter as function of sediment diameter**							
	Outer	**Inner**	***Sed. (mm)***	***0.2***	***0.15***	***0.1***	***0.07***	***0.05***	***0.02***	***0.01***	***0.005***
MHW	0.5	0.32		0.09	0.12	0.18	0.26	0.36	0.89	1.79	3.58
MSL	2	1.16		1.15	1.53	2.30	3.29	4.60	11.50	23.00	46.01
MLLW	0.5	0.20		0.03	0.04	0.07	0.10	0.13	0.34	0.67	1.34