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Characterization of Underwater Sounds Produced by Bucket Dredging Operations

PURPOSE: This technical note presents a characterization of underwater sounds produced by bucket dredging operations in Cook Inlet, Alaska. Both continuous sounds, such as those produced by propellers, pumps, and generators, and repetitive sounds produced by particular dredging events (e.g., dredge bucket striking the channel bottom, jaws of bucket clamping shut) are potential sources of underwater noise. This note examines the intensity, periodicity, and attenuation of emitted sounds from bucket dredging operations and how they are influenced by factors including substrate type, hydrodynamic conditions, equipment maintenance, and skill of the dredge plant operator.

BACKGROUND/INTRODUCTION: In recent years concerns have been raised regarding underwater sounds of anthropogenic origin and their potential impacts on aquatic organisms. Although not the most frequently cited concern, noise-related disturbance has occasionally been cited as justification for environmental windows for Federal navigation dredging projects in both marine and freshwater systems (Reine, Dickerson, and Clarke 1998). Hypothetically, underwater sounds may interrupt or impair communication, foraging, migratory, and other behaviors of marine mammals. It has also been hypothesized that dredging-induced noise could block or delay the migration of fishes through navigable waterways. Few data adequately characterizing sounds emitted by dredge plants exist that would support objective decisions balancing the need to dredge against relative risk to marine or aquatic resources. To obtain data to address this concern, field investigations were undertaken to characterize underwater sounds of a typical bucket dredging operation. Mechanical dredges produce a repetitive sequence of sounds generated by winches and derrick movement, bucket impacts with the substrate, digging into substrate (especially gravel or other coarse material), bucket closing, and the emptying of material into a hopper barge or scow.

Although underwater noise issues have arisen previously, they have been associated primarily with petroleum exploration and industrial construction activities (Richardson et al. 1995). Their consideration in conjunction with navigation dredging has little precedence. The authors are unaware of any published studies that characterize sounds produced by dredges engaged in either navigation channel maintenance or deepening operations. Studies by Greene (1985, 1987), Miles, Malme, and Richardson (1987), and Miles et al. (1986) are among the very few relevant references that exist. Given the general lack of knowledge on the topic, this investigation was undertaken to provide a better technical foundation upon which to assess potential impacts of bucket dredging operations. These findings will be interpreted in a biological response context in an ensuing publication.

METHODS

Field Recording: Underwater acoustic monitoring of bucket dredging (also known as mechanical or clamshell dredging) operations in Cook Inlet, Alaska, was conducted during September 15-17, 1999, and August 16-17, 2000. Sound source audio of the dredging activities was recorded with a RESON TC-4032 low-noise hydrophone with a built-in 10-dB preamplifier, which was connected to a RESON EC-6070 hydrophone audio amplifier via a 50-m deck cable. The EC-6070 was used to amplify the source levels an additional 18 dB (total source amplification of 28 dB) before the audio data were recorded on a TASCAM DA-P1 Digital Audio Tape (DAT) recorder. All hydrophone source audio data were recorded on the left audio track of the DAT recorder, while simultaneous field notes were narrated and recorded on the right audio track. The hydrophone audio data were input into a Sound Technologies analog-to-digital converter where the audio data were digitized and stored on a laptop computer. Sound Technologies Spectra Lab v4.32 audio analysis software was used to display a real-time audio spectrum.

The entire system was powered from two 12-V d-c deep-cycle marine batteries connected to a StatPower pure sine-wave power inverter, which provided a 120-V a-c power source to an uninterruptible power supply (UPS). The UPS in turn directly powered the DAT recorder, laptop computer, and a ProTek model 3033 variable-voltage d-c power supply, which was used to provide 24-V d-c power to the EC-6070 hydrophone audio amplifier. By using the two 12-V d-c batteries as the only power source, the entire system could be operated with the listening vessel completely shut down to a “quiet” mode. This eliminated any noise effect that would be introduced by the engine or generator operating on the vessel used as the listening platform.

A HydroLab water quality surveyor, recording depth, temperature, and salinity data, was suspended 1 m above the hydrophone. The hydrophone cable, HydroLab cable, and suspension line were encased in cable fairing to prevent vibrational strumming. Depth, temperature, and salinity data were used for speed of sound calculations (Table 1). The unit was turned off during actual audio data recording to eliminate noise being generated by the water quality meter.

All data collection sessions were conducted aboard the Manson Dredging Company’s steel hull launch *Margaret M*. Because of extremely high tidal amplitudes and flow velocities in Cook Inlet, it was determined that monitoring the acoustic levels from a fixed or anchored position was not possible. Instead, a “drift” transect approach was used in which the *Margaret M* was maneuvered to a predetermined distance away from the sound source and was then completely shut down and allowed to drift with the current during the recording session. This approach minimized the flow conditions present at the hydrophone, thereby reducing drag imposed on the hydrophone. During the 1999 field study, two separate dredging operations were in progress: the bucket dredge *Viking* working on the navigation channel deepening project and the smaller bucket dredge *Crystal Gayle* performing maintenance dredging at the port docks.

Sound Data Analysis Procedures: Nineteen recording sessions were conducted in September 1999 (Table 1). Multiple recording sessions of ambient sounds were conducted in August 2000. Locations of individual drift transects, determined by differential Global Positioning System coordinates of start and end points, are depicted in Figure 1. Each recording session was digitized from DAT tape using a Sound Technologies analog-to-digital converter and SpectraLab software into MS Windows-compatible 16-bit stereo WAV files with a sampling rate of 44.1 kHz. Each of the 24 WAV files was reviewed and the contents of each file summarized (Table 1). Sessions 1 and 2 were used only to determine appropriate gain settings for the hydrophone audio channel (left) on the DAT recorder and not for audio analysis purposes. Sessions 3-9 and 11-15 taken in September 1999 monitored the *Viking* dredging operations and recorded dredge cycles (defined in the following paragraph) at a number of distance ranges from the dredge. Session 10 recorded a complete dredged

Table 1
Summary of bucket dredging and ambient underwater sound recording sessions

Session	Date M/D/Yr	Monitoring	Duration min:sec	Dredge Cycles	Start Range m	End Range m	Tide	Depth* m	Temperature* °C	Salinity* ppt
1	9/15/99	Set DAT Gain	16:59	N/A	N/A	N/A	Flood	10.0	11.95	9.6
2	9/15/99	Set DAT Gain	1:10	N/A	N/A	N/A	Slack	N/A	N/A	N/A
3	9/15/99	*Viking*	23:31	20	192	451	Slack	9.4	11.93	9.7
4	9/15/99	*Viking*	9:49	8	1,111	926	Slack	9.6	11.93	9.9
5	9/15/99	*Viking*	14:06	11	1,648	1,093	Ebb	9.8	11.84	9.3
6	9/15/99	*Viking*	12:17	11	5,315	4,589	Ebb	10.0	11.48	7.6
7	9/15/99	*Viking*	21:44	15	2,611	1,259	Ebb	10.0	11.51	7.8
8	9/16/99	*Viking*	8:57	9	3,704	2,871	Flood	10.0	11.90	10.0
9	9/16/99	*Viking*	15:48	11	3,305	2,834	Flood	9.8	12.0	10.9
10	9/16/99	*Viking*	35:04	N/A	N/A	N/A	Slack	10.0	12.0	11.0
11	9/16/99	*Viking*	18:13	17	158	582	Ebb	10.0	11.91	10.5
12	9/16/99	*Viking*	8:56	Unknown	9,260	8,371	Ebb	10.0	11.67	8.5
13	9/16/99	*Viking*	8:23	8	7,408	6,852	Ebb	10.0	11.65	8.6
14	9/16/99	*Viking*	7:31	7	5,565	5,130	Ebb	10.0	11.62	8.4
15	9/16/99	*Viking*	57:00	41	3,537	671	Ebb	10.0	11.68	8.6
16	9/17/99	*Crystal Gayle*	67:50	48	1,019	2,982	Flood	9.8	10.97	7.0
17	9/17/99	*Crystal Gayle*	8:37	6	160	347	Flood	9.8	11.06	7.3
18	9/17/99	Ambient	8:34	3	232	602	Flood	7.0	11.85	10.1
19	9/17/99	Ambient	12:52	6	0	0	Flood	6.0	11.82	10.0
20-24	8/16/00	Ambient	1:00	N/A	13,135	13,135	--	--	--	--

* Values measured at the start of a given recording session.

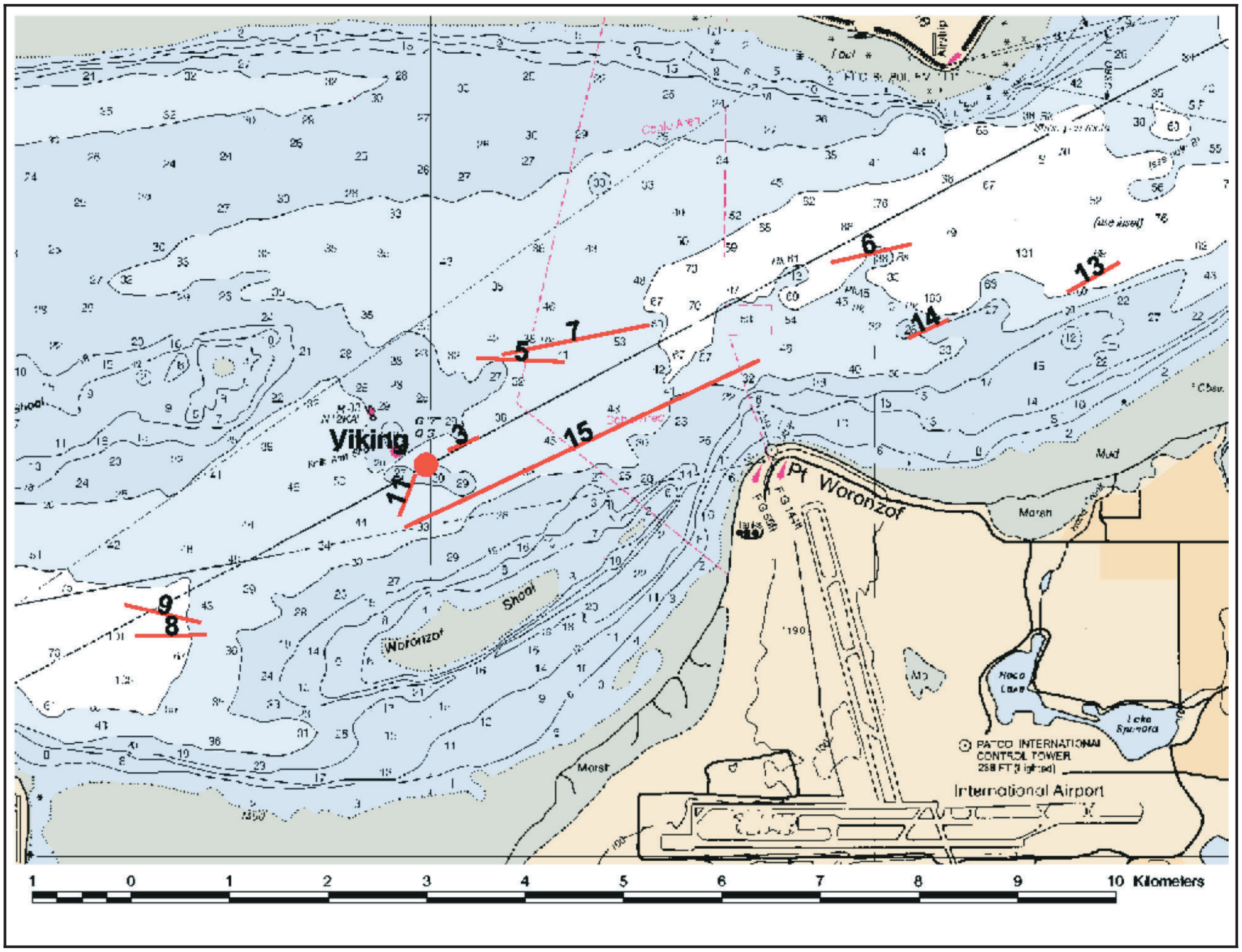


Figure 1. Location of drift transects in Cook Inlet, Alaska

material disposal event from the *Viking* operation. Sessions 16 and 17 monitored the *Crystal Gayle* dredging operations. Sessions 18 and 19 attempted to record ambient conditions in the vicinity of the *Viking*. After an initial assessment of the data, it was determined that more ambient data were required to complete the analysis. Ambient recording sessions 20-24 were completed the following year (August 2000).

Bucket dredges, exemplified by the *Viking*, are relatively stationary (Figure 2). While operating, the dredge swings slowly in an arc across the channel cut as material is excavated. This is accomplished by pivoting the dredge on vertical pilings called spuds that are alternately raised and lowered from the stern corners of the dredge. Cables to anchors set roughly perpendicular to the forward section of the dredge are used to shift the lateral position of the digging area. Periodically, as the cut advances, the anchors are reset. Sounds produced by this type of dredging can best be described as repetitive rather than continuous. Bucket dredging entails lowering the open bucket through the water column, closing the bucket after impact on the bottom, lifting the bucket up through the water column, and emptying the bucket into a barge. For the purpose of sound characterization six distinct "events" composing a single cycle of bucket deployment and retrieval were identified:

- The first event is winch noise as the dredge derrick and bucket swing outward and the bucket is lowered. Although not classified as an event herein, a splash sound caused by the bucket hitting the surface of the water could be detected at relatively short distances from the source. This sound was variable depending on the speed and angle of the bucket as it entered the water.
- In the second event a sudden and often very intense impact sound is produced as the bucket makes contact with the bottom.
- In the third event, a grinding sound is produced as the bucket is closed and the dredged material (coarse sand and gravel) is removed.
- In the fourth event, a snap or clank is often audible as the jaws of the bucket close against each other.
- In the fifth event, more winch noise similar to the initial-event winch noise is audible as the bucket is raised to the surface and the derrick swings over the barge.
- Finally, in the sixth event, material being dumped into the barge may or may not produce an audible sound depending on the level of material existing in the barge. For example, material striking metal in an empty or partially filled barge generally produced an audible sound, whereas material falling upon previously dumped material frequently did not.

Figure 2. Bucket dredge *Viking* operating in Cook Inlet, Alaska

As described, the six sound events are repeated on approximately a 1-min period with minor (e.g., 10-15 sec) variations. Occasional interruptions in the cycles occurred to accommodate barge maneuvering, dumping and washing activities, and equipment maintenance. Figure 3 illustrates a complete cycle encompassing these events for the dredge *Viking*.

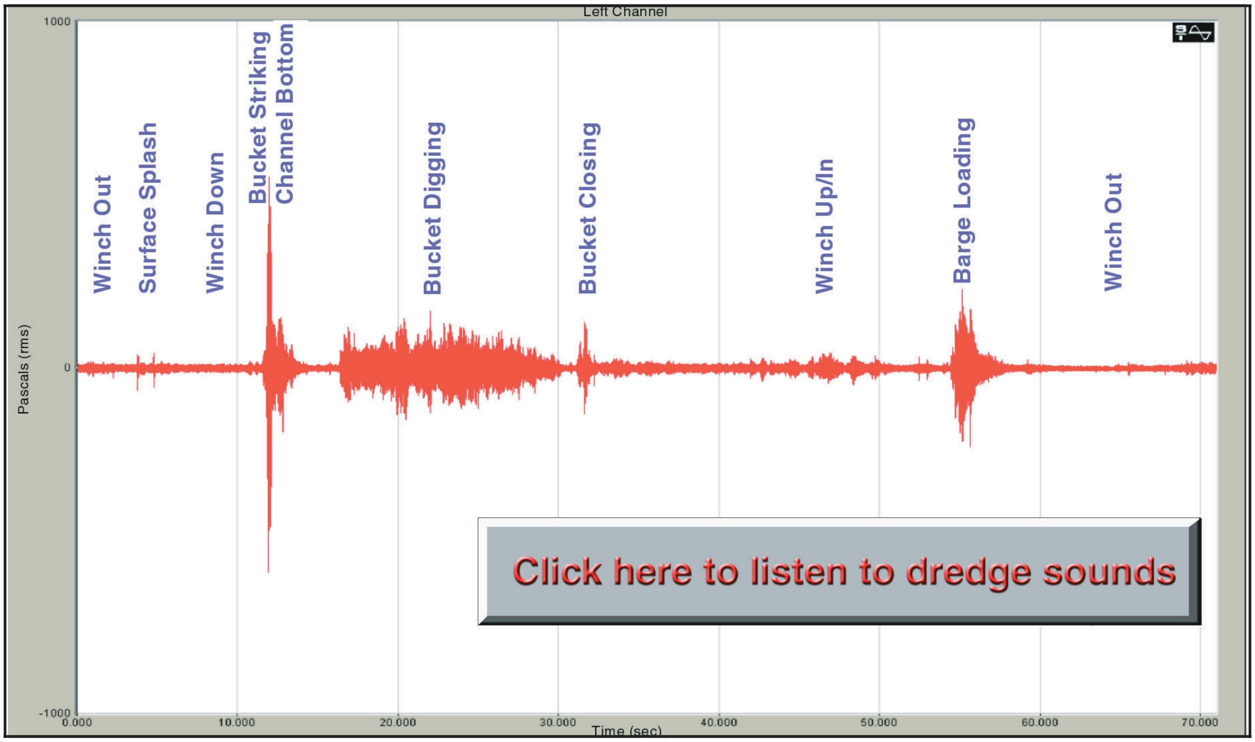


Figure 3. An example pressure waveform for a typical bucket deployment and retrieval cycle

Based upon the six-event sequence, initial data analyses focused only on these six distinct dredge cycle sounds as captured in *Viking* recording sessions 3-9 and 11-15. Session 4 was excluded from this analysis because a tug and barge not related to the dredging operations transited the listening position during almost the entire recording session, thus masking dredge-induced sounds. Session 12 was also excluded from further analysis because no noises characterizing the *Viking* dredging activity were audible at that range above the distant background noise created by barge washing operations from the *Crystal Gayle* dredge operations near the listening positions. Session 13 was conducted at an approximate distance of 7 km from the dredge. Only faint sounds associated with bucket impact on the bottom were audible at this range. Because the remaining sound events of the dredge cycle were indistinguishable at this distance, session 13 was excluded from further analysis.

As previously stated, during the recording sessions, field notes including distance to the dredge or other sound sources were recorded simultaneously on the right channel of the DAT tape. At close ranges the distance was obtained with a laser rangefinder and the distance recorded in meters. When the distance was further than the maximum usable distance for the laser rangefinder (approximately 500 m), the radar unit aboard the *Margaret M* was used and estimated distances were recorded as nautical miles. All distances recorded in nautical miles from the radar were converted to meters, and the estimated distance to the dredge was then interpolated based on recording times, distance notes, and times at known audible events.

Segments of audio sessions containing dredge cycle event sequences representative of as wide a selection of ranges and distances as possible were ordered by increasing range and distance and analyzed. Individual cycles from sessions 6, 8, 11, 14, and 15 were chosen based on the nearest match to the representative range. Each of these cycles was edited from the respective session WAV file, and a new 16-bit mono WAV file with a 44.1-kHz sampling rate was created for each of the individual cycles for the representative range. The WAV files for these individual cycles were reviewed and the sound pressure level (SPL) and frequency relative to the six-event sequence summarized (Tables 2 and 3, respectively).

Dredging Sound Event Characteristics: Cycle WAV files were partitioned into event WAV files. A spectral analysis of each event WAV file was conducted for the bottom contact, digging, bucket closing, and winch in/up event categories using Sound Technologies SpectraLab audio spectral analysis/fast Fourier transform (FFT) software. An FFT block size of 32,768 was used, which produced a frequency resolution of 1.346 Hz. A Hanning window was used to reduce leakage during the FFT analysis, and a 50 percent overlap was used to increase the time resolution for the FFT analysis. Peak and infinite average FFT analyses were conducted for each of the event WAV files and a spectral plot produced.

For each event spectral plot, peak measurements of sound pressure levels (dB rms) are displayed at closest and farthest ranges. A linear trend line was overlaid for each of these plots. Plots indicating peak event noise compared with ambient conditions were also produced. All amplitudes are reported in relative dB units. The SpectraLab software is calibrated to display the relative power levels in dB. Calibration tone data were generated that allow the relative sound signal dB levels to be compared to referenced values (dB re 1 µPa-m). Each plot was produced for a linear frequency range of 3 Hz to 20 kHz. However, due to recording limitations inherent in the equipment, frequencies below 20 Hz were excluded from further analysis.

Because of variation in sound event duration, the number of samples used for FFT transformation analysis varied among specific sound events (e.g., bottom impact versus grab) and among cycles. Three "snaps" as the bucket closed during session 15 (cycles 5, 15, and 16) could not be analyzed because their durations were less than the 32,768 minimum sample size required for FFT analysis.

RESULTS

Ambient Noise: Ambient noise includes a variety of background sources. In Cook Inlet, these included, but were not limited to, wind- and wave-driven turbulence, hydrodynamic noise associated with variable tidal flow conditions, and precipitation. Although not considered as natural background noise, "traffic noise" generated from commercial shipping and recreational or commercial fishing vessels contributes to ambient noise primarily at frequencies <1 kHz (Richardson et al. 1995). Ambient noise may vary with changes in season, location, and time of day. Ambient noise measurements were taken in a location away from the influence of dredging activities. Five 1-min segments were selected and analyzed for inclusion in this technical note. Peak ambient noise occurred at 73.2 dB re 1 µPa-m at a peak frequency of 57.8 Hz. Generally ambient noise averaged 60 dB re 1 µPa-m at frequencies less than 100 Hz and around the mid-50 dB re 1 µPa-m level at frequencies ranging from 100 Hz to 1 kHz.

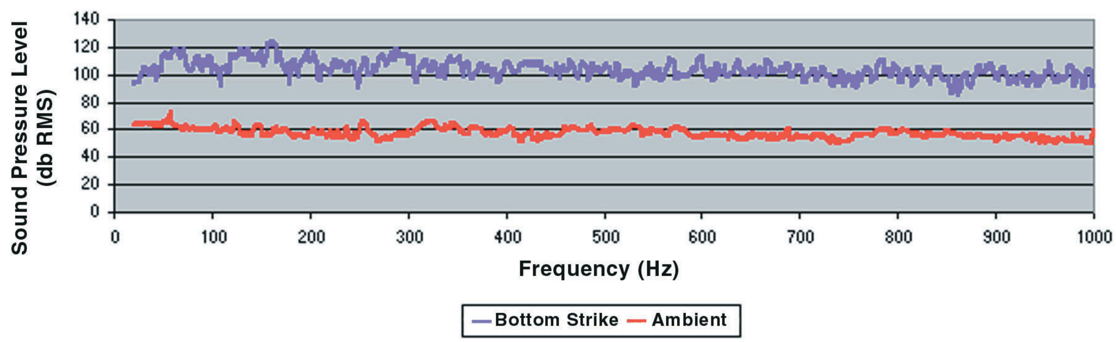
Table 2
Sound pressure levels associated with bucket dredging cycle events measured at increasing distances from the source during dredging operations in Cook Inlet, Alaska

Session	Cycle	Time min:sec	Distance from Source m	Sound Pressure Levels for Distinct Dredging Cycle Events, dB				
				Bottom Contact	Bucket Digging	Bucket Closing	Winch In/Up	Barge Loading
11	1	0:13	158	124.01	113.24	99.25	116.57	108.59
11	3	2:34	213	122.29	114.29	102.50	116.29	103.52
11	5	4:42	250	114.94	115.93	103.85	112.69	107.15
11	7	6:51	299	121.58	111.13	—	113.09	97.72
11	9	8:54	344	115.35	120.17	—	115.80	108.01
11	11	11:02	401	120.81	113.89	103.73	112.25	95.04
11	13	13:14	464	117.02	107.70	104.61	110.78	94.54
15	32	47:08	508	116.91	110.17	—	108.72	86.39
15	28	43:05	552	119.35	112.70	103.95	107.09	93.25
15	39	54:09	607	122.33	108.95	102.72	107.10	—
15	25	39:37	652	117.62	111.40	109.12	103.39	—
15	23	37:30	712	118.41	110.14	91.50	111.82	—
15	22	36:26	783	117.39	108.97	99.26	110.09	89.49
15	19	33:27	888	118.94	107.52	94.61	106.48	87.33
15	17	31:27	1,065	115.69	107.96	—	102.90	—
15	16	30:32	1,114	113.50	103.70	—	100.99	—
15	15	29:31	1,182	107.45	104.07	—	96.38	82.47
15	13	27:19	1,313	113.52	110.81	104.46	94.73	—
15	12	26:18	1,404	108.14	108.17	98.84	96.34	—
15	11	25:13	1,482	115.29	110.69	99.49	98.01	—
15	7	21:11	1,751	103.28	104.50	89.12	101.69	—
15	5	19:08	1,965	108.54	100.83	—	103.24	—
8	7	6:32	3,017	116.94	95.11	84.52	—	—
8	1	0:56	3,586	101.03	—	—	—	—
6	11	10:56	4,589	102.7	95.12	—	—	—
6	6	5:53	5,036	94.97	94.97	—	—	—
14	2	1:09	5,479	100.33	98.78	93.87	—	—

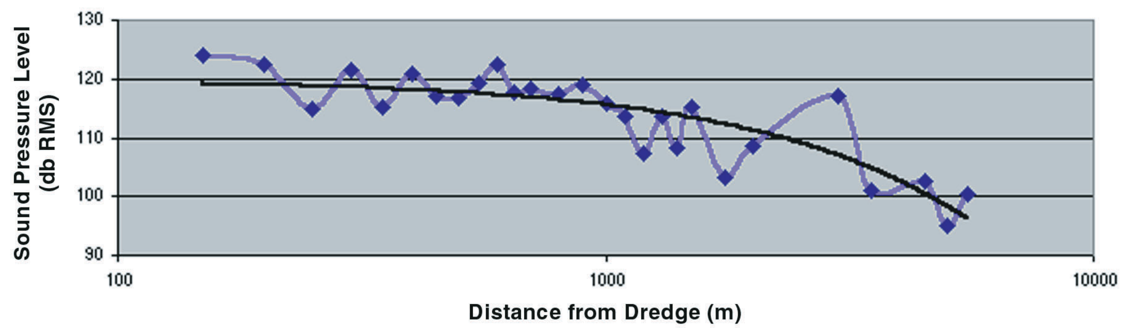
Table 3
Sound frequencies measured at increasing distances from the source for bucket dredging cycle events during dredging operations in Cook Inlet, Alaska

Session	Cycle	Time min:sec	Distance from Source m	Sound Frequencies for Distinct Dredging Cycle Events, Hz				
				Bottom Contact	Bucket Digging	Bucket Closing	Winch In/Up	Barge Loading
11	1	0:13	158	162.85	40.38	316.27	34.99	82.10
11	3	2:34	213	178.99	192.45	347.22	33.65	25.57
11	5	4:42	250	146.70	122.47	341.84	33.65	733.48
11	7	6:51	299	60.56	53.83	—	33.65	29.61
11	9	8:54	344	223.41	165.54	—	40.38	434.70
11	11	11:02	401	98.25	52.49	40.38	33.65	605.62
11	13	13:14	464	94.21	52.49	693.10	34.99	32.30
15	32	47:08	508	145.35	48.45	—	45.76	1,436.0
15	28	43:05	552	88.82	275.89	279.93	48.45	44.41
15	39	54:09	607	138.62	371.45	903.05	56.53	—
15	25	39:37	652	87.48	131.89	551.79	34.99	—
15	23	37:30	712	61.91	48.45	263.78	51.14	—
15	22	36:26	783	87.48	104.97	571.98	52.49	532.95
15	19	33:27	888	91.52	99.59	51.14	52.49	59.22
15	17	31:27	1,065	316.27	156.12	—	49.80	—
15	16	30:32	1,114	145.35	87.48	—	56.53	—
15	15	29:31	1,182	212.64	130.55	—	49.80	60.56
15	13	27:19	1,313	213.99	150.73	668.88	47.10	—
15	12	26:18	1,404	99.59	222.06	582.74	48.45	—
15	11	25:13	1,482	157.46	191.11	226.10	48.45	—
15	7	21:11	1,751	367.41	203.22	565.25	49.80	—
15	5	19:08	1,965	72.68	169.57	—	48.45	—
8	7	6:32	3,017	74.02	44.41	40.38	—	—
8	1	0:56	3,586	65.95	—	—	—	—
6	11	10:56	4,589	95.55	165.54	—	—	—
6	6	5:53	5,036	72.68	137.27	—	—	—
14	2	1:09	5,479	166.88	157.46	392.98	—	—

Bucket Striking Channel Bottom: Peak sound pressure levels (dB rms) produced by a dredge bucket striking the channel bottom in mixed coarse sand and/or gravel are compared to ambient conditions in Cook Inlet in Figure 4. Distance to the dredge plant source was 150 m with peak SPL (dB rms) measured for the event. These parameters were used for the examples given for each dredging event. Peak SPL was measured at 124.0 dB re 1 μPa-m occurring at a peak frequency of 162.8 Hz, or 50.8 dB re 1 μPa-m above peak ambient conditions (peak 73.2 dB re 1 μPa-m at <100 Hz; average 57.5 dB re 1 μPa-m at <1 kHz). This event produced the most intense sounds of all events in the dredging cycle (Figure 3). Peak SPL calculated at the 150-m listening station indicated an approximate difference of +8 dB compared with a winch in/out event, and +25 dB compared with a bucket closing event.



a. Ambient conditions



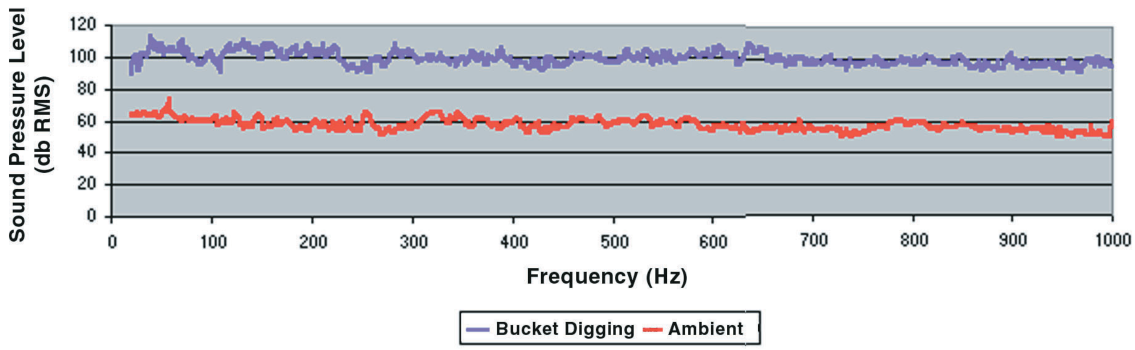
b. Attenuation with distance from the point source

Figure 4. Sound pressure level produced by dredge bucket striking the channel bottom (coarse sediment and/or gravel) as measured over ambient conditions and its attenuation with distance from the point source in Cook Inlet, Alaska

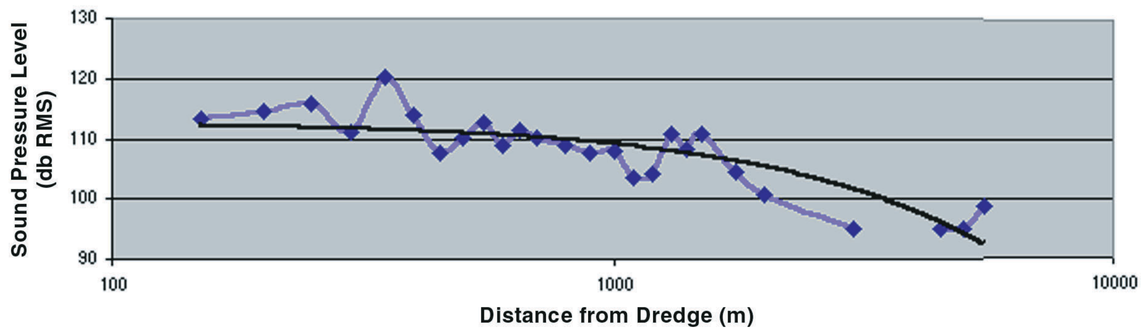
Peak SPL measurements were also recorded at varying distances from the dredge (Table 2). Figure 4 illustrates the attenuation of sound over distance for the bottom strike event. A reduction of 30 dB re 1 μPa-m occurred between the 150-m and 5,000-m listening stations (94.97 dB re 1 μPa-m; peak frequency 72.7 Hz). Limited data indicated only faintly audible sounds for this event at the 7-km range, indicating the near outer limits of detectability in Cook Inlet for this type of dredge plant.

Bucket Digging: This event is characterized by a grinding noise as the bucket jaws dig into the sediment. Sound pressure levels (dB rms) for the “grab event” are compared to ambient conditions in Figure 5. At the 150-m listening station, peak SPL was measured at 113.2 dB re 1 μPa-m at a peak frequency of 40.4 Hz, or 40 dB re 1 μPa-m above peak ambient conditions. However, a maximum reading of 122.3 dB re 1 μPa-m was recorded at the 600-m listening station. This may have resulted from the bucket grabbing into a patch of harder gravel substrate at this listening station. Peak intensity for this event, measured at the 150-m listening station, was 10.8 dB lower than that recorded for the bucket striking the bottom event.

Figure 5 illustrates the attenuation of SPL produced by the digging event with increasing distance from the sound source. The plot shows a decrease in SPL (18 dB) from 113 dB re 1 μPa-m (150 m) to a low of 94.97 dB re 1 μPa-m at the 5,000-m range.



a. Ambient conditions



b. Attenuation with distance from the point source

Figure 5. Sound pressure level produced by dredge bucket digging into coarse sediment as measured over ambient conditions and its attenuation with distance from the point source in Cook Inlet, Alaska

Bucket Closing: This event occurs when the jaws of the bucket close against each other. In contrast to other dredging events, bucket closing does not always produce an audible sound as noted in Table 2. Figure 6 illustrates the SPL (dB) generated during a dredge bucket closing event compared with ambient conditions. In general, this event produced the least intense sounds. At the 150-m listening station, SPL was measured at 99.25 dB re 1 μPa-m at a peak frequency of 316.3 Hz, or 26 dB re 1 μPa-m above peak ambient conditions. In comparison with other dredging events recorded at the 150-m listening station, SPLs for bucket closing were on average 9 dB re 1 μPa-m lower than barge loading events and 25 dB re 1 μPa-m lower than bucket striking the bottom events. Peak SPL generated during bucket closing occurred at much higher peak frequencies (as high as

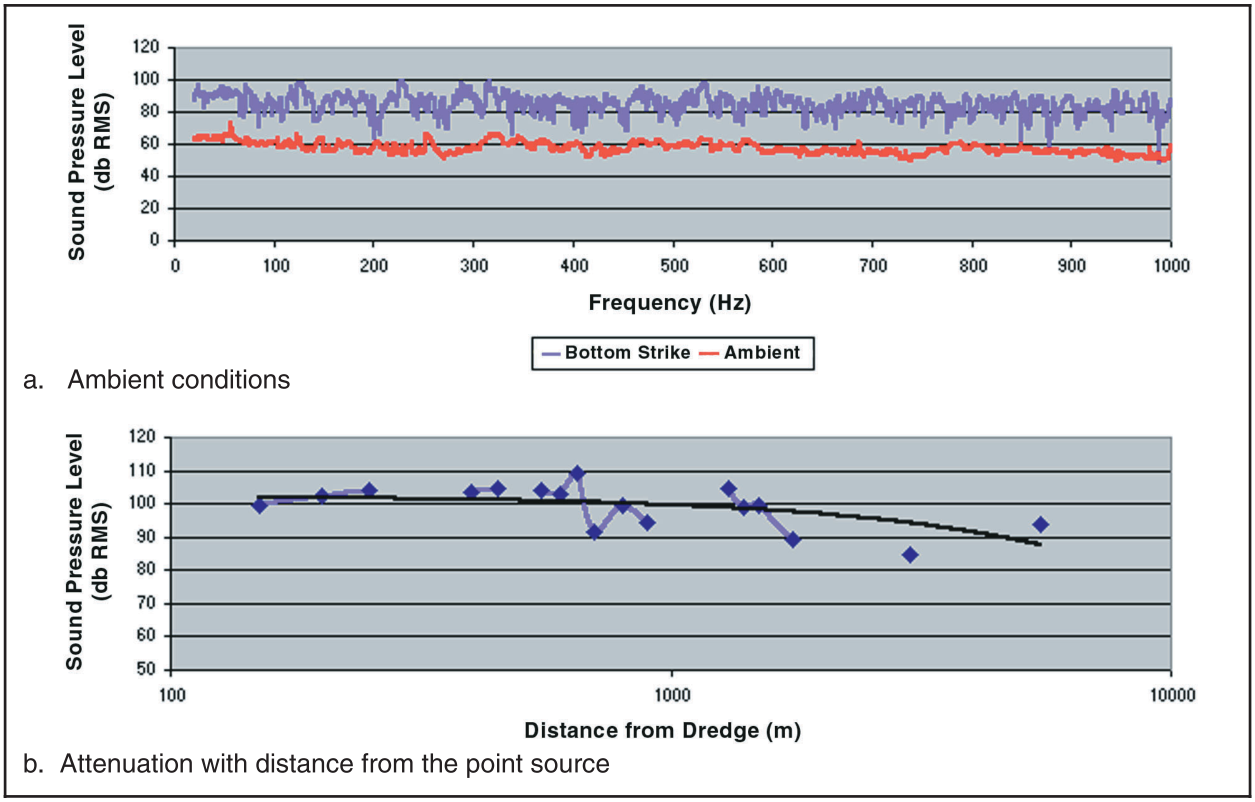
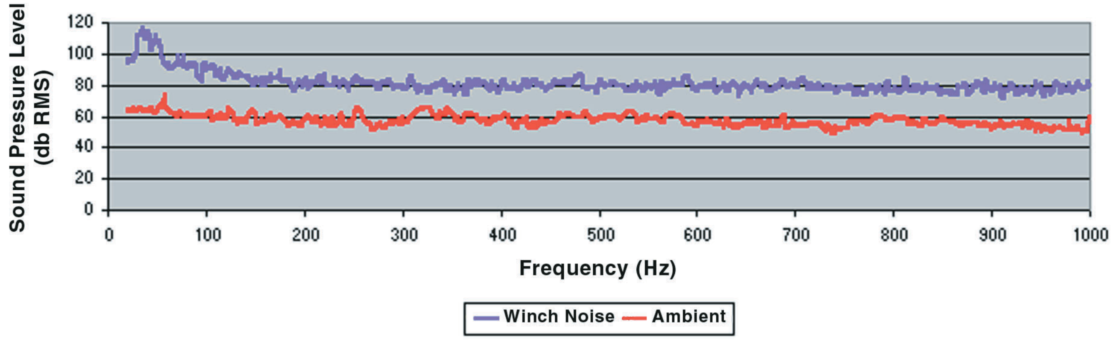


Figure 6. Sound pressure level produced by dredge bucket closing as measured over ambient conditions and its attenuation with distance from the point source in Cook Inlet, Alaska

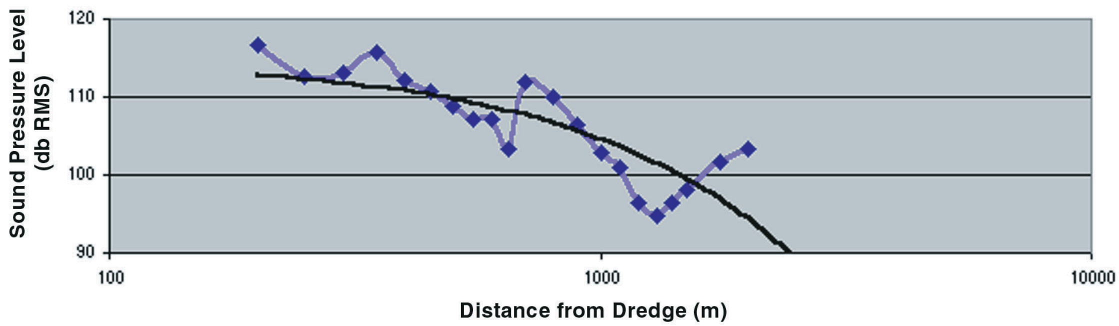
903.1 Hz) compared with other dredging events (Table 3). Figure 6 illustrates the attenuation of sound pressure levels measured over distance (150-5,500 m) for this event.

Winch In/Out: Winch noise is produced as the bucket is either lowered through the water column or raised to the surface in combination with the derrick as it swings over to the barge in preparation to release material into the hopper barge. SPL generated by the operation of the winch and derrick movement measured over peak ambient conditions is shown in Figure 7. At the 150-m listening station SPL was measured at 116.6 dB re 1 µPa-m at a peak frequency of 34.99 Hz, or 43.4 dB re 1 µPa-m above peak ambient conditions. The lowest SPL for winch noise occurred at 1,300 m at 94.7 dB re 1 µPa-m at a peak frequency of 47.1 Hz, a reduction of 21.8 dB re 1 µPa-m. SPL measurements did increase somewhat from 1,400 m (96.3 dB re 1 µPa-m) to 2,000 m (103.2 dB re 1 µPa-m). This increase at the 2,000-m range was still 13.3 dB re 1 µPa-m lower than readings taken at the closest listening station. Figure 7 illustrates the attenuation of SPL (dB rms) from the closest (150 m) to the farthest (2,000 m) ranges. Winch noises produced lowest peak frequencies compared with other dredging events (33.6 to 56.5 Hz).

Dumping Material into Barge: Sounds associated with this aspect of dredging were dependent on the volume of material in the barge at the time the measurements were taken. Material placed into an empty or partially full barge frequently generated audible sounds, whereas material placed upon existing material sometimes did not, probably due to sounds being buffered as they were transmitted through the hull. At the 150-m listening station, SPL was 108.6 dB re 1 µPa-m at a peak



a. Ambient conditions



b. Attenuation with distance from the point source

Figure 7. Sound pressure level produced from winch-generated noise measured over ambient conditions and its attenuation with distance from the point source in Cook Inlet, Alaska

frequency of 82.10 Hz, or 35.4 dB re 1 µPa-m above peak ambient conditions (Figure 8). This dredging event was generally quiet, producing slightly more intense sounds than the bucket-closing event, which was less than 10 dB lower at 99.25 dB re 1 µPa-m. SPL measurements for other dredging events at this distance were higher by 5 dB re 1 µPa-m for bucket digging and 15.4 dB re 1 µPa-m for bottom striking. Figure 8 illustrates a rapid attenuation of noise for this event, falling to near-ambient conditions beyond 1,200 m from the source.

Emptying Barge at Placement Site: Whereas the preceeding events are repetitive on a time scale of minutes during active dredging, emptying the barge occurs much less frequently, generally at intervals of several hours. Underwater sound data were collected while drifting near the placement site, which was several km from the dredging site. At the time when the split-hull barge opened to release the dredged material, the distance to the source was measured to be 316 m. The placement event lasted approximately 60 sec. Figure 9 illustrates the sounds generated by the barge-emptying event compared with ambient conditions. Peak SPL (dB rms) was measured at 108.7 dB re 1 µPa-m at 45.8 Hz. From 20 to 1,000 Hz, lowest SPL was measured at 96 dB re 1 µPa-m. Noise levels ranged from 22.8 to 34.8 dB re 1 µPa-m above peak ambient conditions.

Bucket Dredging in Unconsolidated Sediments: The dredge *Crystal Gayle* was performing maintenance dredging operations near the port facility in an area characterized by soft sediments. Peak SPL (dB rms) for a bottom strike event in soft sediment was measured at 107 dB re 1 µPa-m at 91.5 Hz. At a range of 555 m, peak noise levels were 11.6 dB re 1 µPa-m quieter than comparable

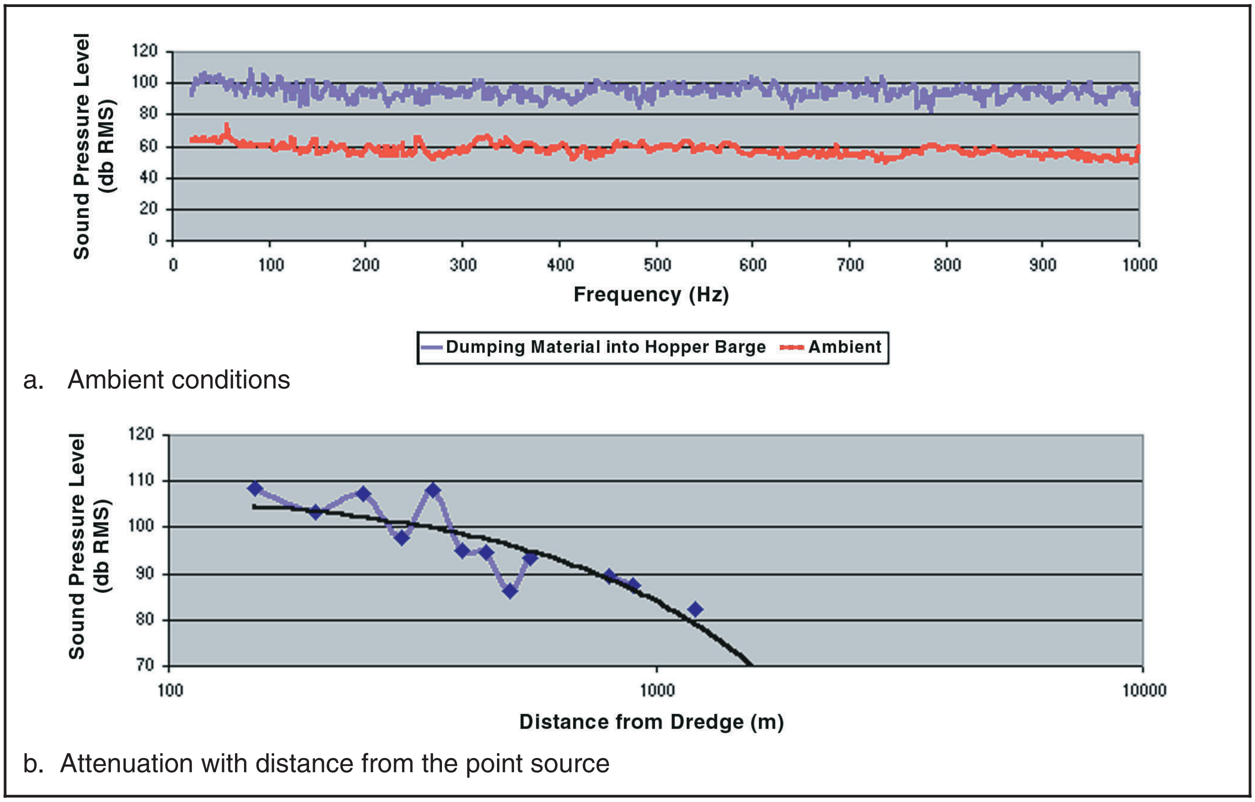
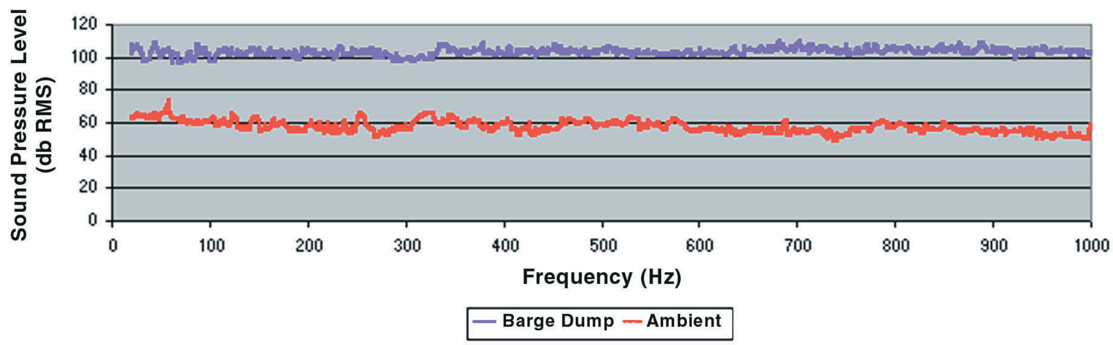


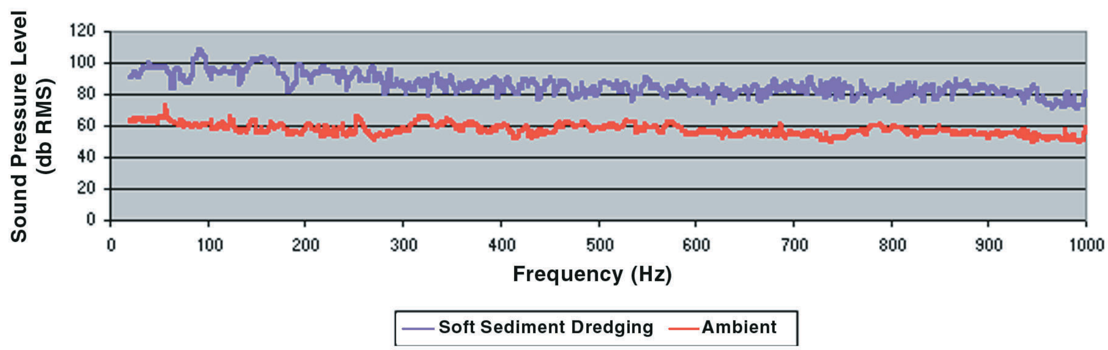
Figure 8. Sound pressure level produced from dumping material into hopper barge measured over ambient conditions and its attenuation with distance from the point source in Cook Inlet, Alaska

peak SPL measurements for the *Viking* dredging in coarse sediments (119.4 dB re 1 μPa-m). Sound attenuation for the *Crystal Gayle* events occurred very rapidly, falling to 90.6 dB re 1 μPa-m at the 2,900-m range, or approximately 17 dB above peak ambient levels (Figure 9). In comparison, bottom strike events in soft sediment ranged from 11.6 dB re 1 μPa-m quieter at 555 m to 27 dB re 1 μPa-m quieter at 2,900 m than peak SPL measurements recorded for bottom strike events at similar distances in coarse substrate.

DISCUSSION: The majority of underwater sounds produced by bucket dredging operations monitored in this study were in relatively low frequency ranges, primarily 20 to 1,000 Hz. Noise levels decreased with increasing distance from the source. SPL (dB rms) diminished from 15 to 30 dB re 1 μPa-m at 150-m and 5,500-m distances, respectively. In this study dredge sounds were audible at 5,500 m, whereas at 7,000 m only the most intense event, that of the bucket striking the bottom, remained faintly audible. The apparent maximum detection distance of 7 km observed in this study is probably influenced by a number of factors. Much greater detection distances for dredge noise above ambient were reported by Greene (1987, 1985), who measured broad-band (20-1,000 Hz) noise emitted by a hydraulic cutterhead-pipeline (cutter-suction transfer) dredge at ranges extending to 25 km in the Beaufort Sea. Miles, Malme, and Richardson (1987) and Miles et al. (1986) recorded sounds produced by a bucket dredge, noting most intense sounds in the 1/3 octave at 250 Hz, ranging from 150 to 162 dB re 1 μPa-m. Cook Inlet waters throughout the study area were extremely turbid. High prevailing suspended sediment concentrations may have a pronounced sound-scattering effect, thereby reducing sound detection distances rapidly compared with sounds emitted from sources in



a. Emptying hopper barge at the placement site



b. Dredging in soft sediment

Figure 9. Sound pressure level produced when emptying hopper barge at the placement site and when dredging in soft sediment as measured over ambient conditions in Cook Inlet, Alaska

clear oceanic waters. For example, Richards, Heathershaw, and Thorne (1996) reported that concentrations on the order of 20 mg/L could cause an attenuation of 3 dB over a path length of 100 m at 100 kHz. Although water samples were not taken during this study, suspended sediment concentrations greatly surpass these levels in Cook Inlet. Thus site-specific conditions should be an important consideration in environmental assessments of dredging-related underwater noise elsewhere.

Miles, Malme, and Richardson (1987) and Miles et al. (1986) reported that the loudest sounds measured in their study were produced during the winching of the loaded bucket up through the water column. In contrast, the winching events in data collected for this technical note were relatively weak in terms of acoustic energy compared with that of the bucket striking the bottom event. This variability indicates that the condition of the dredge plant greatly affects the character of the sounds produced. Poorly maintained or lubricated mechanical gear can potentially generate very intense sounds.

The character of bucket dredging sounds also appears to be greatly influenced by the granulometry of the sediments being dredged; i.e., a bucket impacting coarse sands and gravels, as exemplified by the dredge *Viking* performing deepening work in coarse sand and gravel, produced very different, less intense sounds from those of the dredge *Crystal Gayle* performing maintenance work in unconsolidated mud.

CONCLUSION: Navigation dredging is common in coastal waters. Measured sound levels from bucket dredging activities can exceed ambient levels out to considerable distances as was seen in this study. Sounds produced from bucket dredging operations were quite variable, depending on the phase of the operation. In this study the strongest sound was associated with the bucket striking the channel bottom, although absolute sound levels were highly dependent on substrate type. Dredging in coarse sediments produced the most intense sounds, whereas bottom contact in unconsolidated mud emitted considerably less intense sound. The second strongest sound source was the winch motor that pulled the loaded clamshell bucket back to the surface. This noise exceeded the bucket striking the channel bottom event when dredging in soft sediment. The bucket digging event produced noises at peaks similar to those generated by the winch motor, but only when dredging in coarse sediment. In comparison with other dredging events, the bucket closing event generally produced the least intense sounds. Additionally, sounds from this event were sporadic and were not always audible. Of all events evaluated, noise produced from dumping material into the hopper barge attenuated most rapidly with increasing distance from the sound source. No audible sounds from this event were detected beyond 1,200 m.

When estimating the level of noise that may be introduced into a shallow coastal environment from bucket dredging, consideration of sediment type may be very important. In general, considerably less noise is generated when dredging in soft sediment. Maintenance dredging produced sounds that extended outward only to 3,000 m in this study, and these were most audible for the bucket striking the channel bottom. Many of the other events such as digging into the soft sediment were audible at comparatively short distances from the sound source. Other factors that may be important in bucket dredge sound production include size of the bucket (not directly evaluated herein) and state of repair of the various types of equipment involved. Additional factors influencing received noise levels include hydrodynamic conditions, notably prevailing suspended sediment loads and sea state conditions, as well as skill of the dredge plant operator. With respect to the latter, considerable sound variation was observed among repetitive dredge cycles due to variation in speed of the winching operations, the position and orientation of the bucket relative to the water surface when the downward plunge began, and the consequent angle at which the bucket impacted the bottom.

These data should provide a better foundation for consideration of environmental concerns stemming from underwater noise associated with bucket dredging operations. Sounds produced by hydraulic hopper draghead dredges and hydraulic pipeline cutterhead dredges will be characterized in ensuing notes.

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