Prepared in cooperation with the Great Lakes Restoration Initiative

Seismic Data Collection from Water Gun and Industrial Background Sources in the Chicago Sanitary and Ship Canal Area, Illinois, 2011

Data Series 938

U.S. Department of the Interior
U.S. Geological Survey

Front cover: Water gun setup in Chicago Sanitary and Ship Canal near Lemont, Illinois, September 2011. For more details, see figure 6.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

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Seismic data for the Chicago Sanitary and Ship Canal are available at http://dx.doi.org/10.3133/ds938.

Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
cubic inch (in^3)	16.39	cubic centimeter (cm^3)
cubic inch (in^3)	0.01639	cubic decimeter (dm^3)
cubic inch (in^3)	0.01639	liter (L)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
bar	100	kilopascal (kPa)

Seismic Data Collection from Water Gun and Industrial Background Sources in the Chicago Sanitary and Ship Canal Area, Illinois, 2011

By William S. Morrow,[1] Philip J. Carpenter,[2] and Ryan F. Adams[1]

Abstract

The water gun is a tool adapted from deep marine geophysical surveys that is being evaluated for use as an acoustic fish deterrent to control the movement of invasive marine species. The water gun creates a seismic signal by using a compressed air discharge to move a piston rapidly within the water, resulting in an implosion. This energy pulse may be able to modify fish behavior or destroy marine life, such as the Asian carp, at some distance. The effects of this energy pulse on structures in the Chicago Sanitary and Ship Canal (CSSC), such as canal walls, shore lines, and lock structures, are not known. The potential effects of the use of a water gun on structures was identified as a concern in the CSSC and was assessed relative to existing background sources during this study. During September 2011, two water guns with piston sizes of 80 and 343 cubic inches, respectively, were tested in the CSSC at varying pressures and distances from a canal wall consisting of dolomite and dolomite setblock. Seismic data were collected during these water gun firings using geophones on land, in boreholes, and at the canal wall interface. Data were collected at varying depths in the canal water using hydrophones. Seismic data were also collected during the occurrences of barge traffic, railroad traffic located near the electric fish barrier in Lemont, and coal-loading operations at a coal power plant near the electric fish barrier. In general, energy produced by barge and railroad sources was less than energy created by the water gun. Energy levels produced by coal-loading operations at least 200 feet from geophones were approximately four times lower than energy levels measured during water gun operations.

[1]U.S. Geological Survey.

[2]Northern Illinois University.

Introduction

The water gun is a device that produces a seismic energy source by moving a 1 to 343-cubic-inch (in^3) piston rapidly within the water, creating an implosion, shock wave, and a resulting seismic energy pulse. The water gun may be able to deter or kill fish (Gross and others, 2013; Keevin and Hempen, 1997). The Asian carp is an aquatic invasive species that is extending their habitat upstream in the Illinois River. The Illinois River is connected with Lake Michigan through the Chicago Area Waterway System (CAWS) and the Chicago Sanitary Ship Canal (CSSC). This waterway connection makes possible the introduction of Asian carp into Lake Michigan. Because of this possible ability to destroy or repel marine life at some distance, water guns have been proposed to be used as a method to control or remove Asian carp in the vicinity of the electric fish barriers and other possible locations in CAWS and downstream of the CAWS. The magnitude and potential impact of vibrations (energy generated) resulting from the use of water gun(s) on structures, such as the lock controlling works, the electric barrier, and canal walls, is unknown. Seismic data were collected from an area of the CSSC during testing of the 80- and 343-in^3 water guns to measure vibrations to initially assess potential effects produced relative to other background sources, such as barges, railroad traffic, and coal-loading operations. Recordings of seismic data produced from other sources present in the vicinity of the CSSC include: (1) barge traffic along the CSSC, (2) railroad traffic located near the electric fish barrier in Lemont, and (3) coal-loading operations at a coal power plant also near the electric fish barrier. The data were received with geophones and hydrophones on the surface, in boreholes, along the canal wall, and within the canal water. These seismic data records are presented here to give a comparative energy output of the water gun relative to existing background energy, so possible effects on the structures and canal walls from the water gun use may be evaluated relative to current vibration sources. This project was funded through the Great Lakes Restoration Initiative as administered by the U.S. Environmental Protection Agency.

Purpose and Scope

The purpose of this geophysical investigation is to improve the understanding of the relative energy output of the water gun that could potentially be used to control invasive species in the CAWS by presenting geophysical data that can be used to characterize ground vibrations resulting from the use of a water gun as a fish deterrent in the CAWS. Ground vibration intensity, in terms of particle velocities and frequencies produced by the water gun, can be compared to the ground vibrations produced by barge traffic and industry near the fish barrier (coal power plant and rail traffic). Seismic energy from these sources was measured by geophones on the land surface, in boreholes, and at the canal wall; hydrophones were used in water. These data show the relative difference in energy among the sources, but determining whether structures would be damaged, such as canal walls, is beyond the scope of this report. Seismic data discussed in this report are stored online in the SEG-2 format, a standard geophysical data file format. Seismic data can be accessed through standard geophysical software capable of reading SEG-2 files. Software capable of reading SEG-2 format is also freely available and documented in U.S. Geological Survey (USGS) Open-File Report 03-141 (Ellefsen, 2003), available at http://pubs.usgs.gov/of/2003/ofr-03-141. Other open-source software, such as Geopsy (available at http://www.geopsy.org/), are available to read SEG-2 formatted data. The digital data are available at http://dx.doi.org/10.3133/ds938/.

Chicago Sanitary and Ship Canal Site Study Area with Borehole, Geophone, and Hydrophone Locations

The location for testing within the Chicago Sanitary and Ship Canal (CSSC) was chosen based on the site being topographically and geologically similar to the electric fish barrier site. Dolomite or dolomite setblock comprises the channel walls. The width of the canal at the testing point was approximately 167 ft, with an approximate canal depth of 25 ft during testing. The location is approximately 5 miles upstream from the electric fish barrier near River Mile 301.5 (fig. 1).

Borehole Locations

Three boreholes were installed at the site using mud rotary drilling. The locations of the boreholes are in an approximate straight line at 5, 35, and 100 ft away from the north canal wall. All three boreholes had water levels approximately the same elevation as the CSSC water level.

The borehole 5 ft from the canal wall (3-in. diameter) was drilled to 29.5 ft below ground surface (bgs) with 10 ft of casing (top portion). Stickup was 0.1 ft above the ground surface.

The borehole 35 ft from the canal wall (4-in. diameter) was drilled to 39.4 ft bgs with 20 ft of casing. Stickup was 1.2 ft above ground surface.

The borehole 100 ft from the canal wall (4-in. diameter), was drilled to 35 ft bgs with 15 ft of casing. Stickup was 0.24 ft above ground surface. See figure 2.

Geophone Locations

Three-component (3C) geophones consisting of two horizontal-motion sensors and one vertical-motion sensor were deployed at the land surface adjacent to boreholes. These land-surface geophones were leveled and coupled to the ground using three spikes affixed to the bottom of the geophone. The longitudinal axis of the geophones (channel 2) was oriented with the pointed end of the geophone, which was perpendicular to the canal.

Three-component downhole geophones (two horizontal components and one vertical component) were secured in position using springs expanded against the borehole wall in the three boreholes located at 5, 35, and 100 ft from the canal. Two geophones were installed at each borehole, with one geophone 5 ft bgs and the other deeper geophone ranging from 20–25-ft bgs to approximate the elevation of the water gun.

One 3C downhole geophone was installed in a 3-in-diameter polyvinyl chloride (PVC) pipe that was secured against the side of the canal wall. The 3C geophone was installed approximately 2 ft below water surface.

Hydrophone Locations

Three hydrophones were installed approximately 3 ft away from the canal wall. These hydrophones were installed on one cable and were spaced at 8-ft intervals. The approximate depths of these hydrophones were at 3, 11, and 19 ft below water surface (fig. 2).

Methodology

Water gun and background-barge data acquisition occurred from September 26–29, 2011. Industrial-background seismic-data acquisition from the coal power plant and the railroad adjacent to the electric fish barrier occurred on October 20 and November 1, 2011 (fig. 3). Personnel involved with data collection were from the USGS Illinois Water Science Center (Urbana and DeKalb, Illinois), Northern Illinois University (NIU), the Northern Rocky Mountain Science Center (Missoula, Montana), and Bolt Technology (Norwalk, Connecticut).

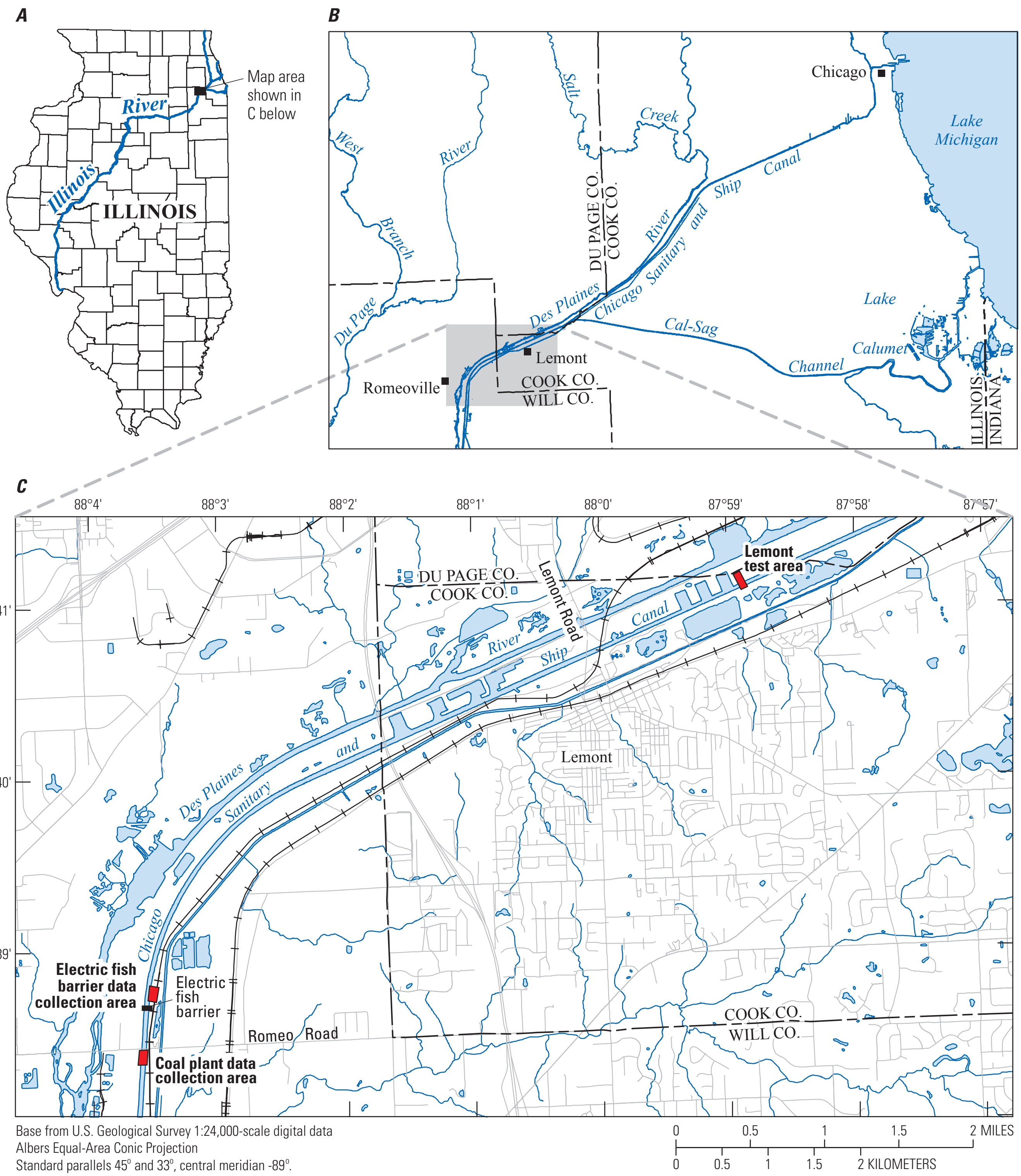

Figure 1. Location of the Lemont test area, data collection areas, and the electric fish barrier on the Chicago Sanitary and Ship Canal between Romeoville and Lemont, Illinois.

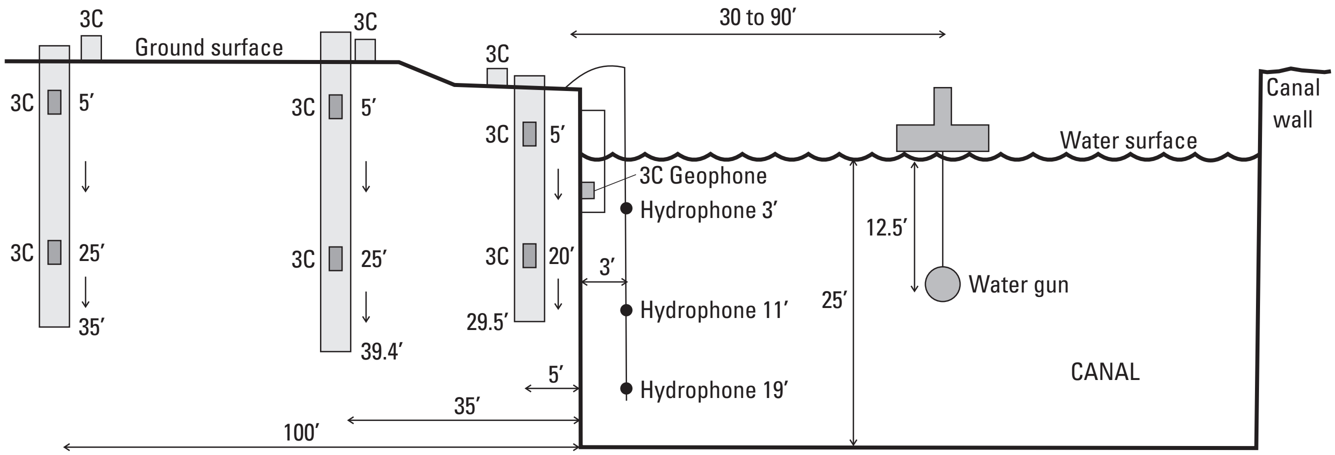

Figure 2. Schematic of the Lemont test area.

Seismic Data Collection

Data were collected using a Geometrics Geode 24-channel seismograph with single Geode operating software (SGOS). A multiple Geode operating software (MGOS) was used on the final day of testing. Data collection was initiated manually. All geophones and hydrophones were channeled through routing switchboxes to the Geode seismograph, which digitized and recorded all signals. The Geode data were collected using the upper range of the low gain setting on the Geode seismograph, resulting in 24 decibels of gain before signal amplification, a signal magnification factor of approximately 16. Sampling time length for water gun data collection was either 8 seconds (s) at a 0.125-millisecond (ms), or 8 s at a 0.5-ms sampling interval. Sampling time for background collection was 240 s at a 16-ms sampling interval.

Geophones

All geophone data are output in millivolts (mV). Three-component geophones manufactured by RT Clark, having a frequency of 10 Hertz (Hz), coil resistance of 395 ohms, and a sensitivity of 27.5 volts (V)/(m/s), were used for all surface locations. Mark Products 3C, horizontal, and vertical geophones, owned by Northern Illinois University, were also deployed. These included the 3C L-15B geophones (4.5-Hz natural frequency), the vertical component L-10B (4.5-Hz natural frequency), L-40 A3 geophones (40-Hz natural frequency), and the horizontal L-28LBH geophones (4.5-Hz natural frequency).

Downhole 3C land geophones manufactured by RT Clark, having a frequency of 10 Hz, coil resistance of 395 ohms, and a sensitivity of 27.5 V/m/s, were used in the three boreholes and the 3-in. PVC pipe affixed to the side of the canal wall. The geophones were held in place at the desired elevation by attached steel springs that were manually released causing the springs to expand and seat firmly against the borehole.

Hydrophones

The primary hydrophones were three hydrophones constructed as one in-line cable with a spacing of 8 ft between hydrophones. The hydrophones were High Tech HTI-96-Min hydrophones with no preamplifier. The hydrophones have a sensitivity of 8.9 V/bar. All hydrophone data are in mV.

Prior to using the hydrophone string for recording, two “sacrificial” OYO Geospace MP–24–L3 hydrophones, with a sensitivity of 7.5 V/bar, were used to determine if hydrophone usage was feasible at the shot pressure and distance to the water gun. Water gun shots were fired at 30-ft distances to determine potential damage to the hydrophones. No rupturing or damage was determined to have occurred and the High Tec hydrophone string was determined to be safe to use at a distance of 30 ft.

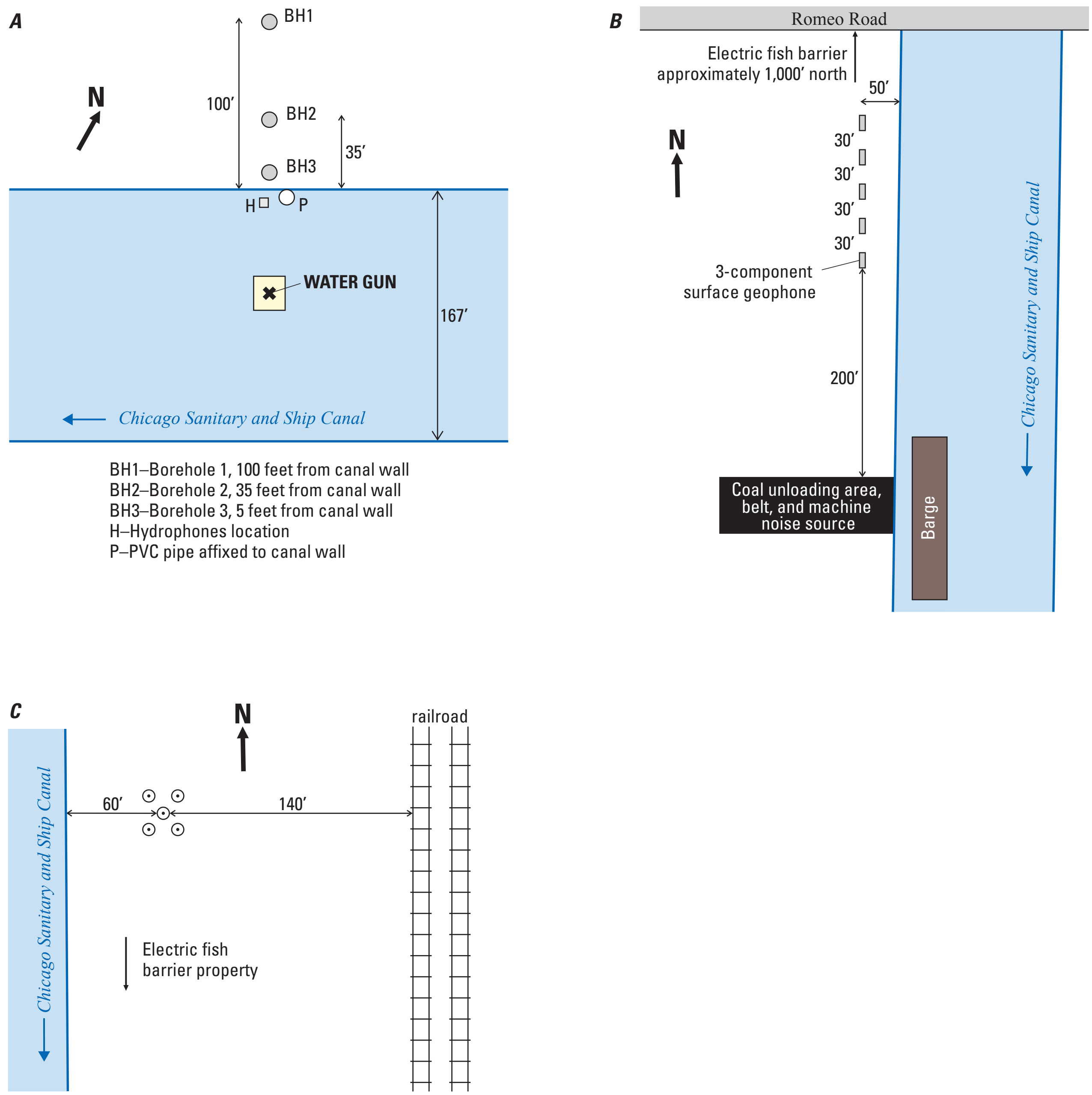

Figure 3. Closeup view and equipment at *A*, the Lemont test area; *B*, Coal plant data collection area; and *C*, Electric fish barrier data collection area, on the Chicago Sanitary and Ship Canal between Romeoville and Lemont, Illinois.

Water Gun Source

Two water guns were used in the test—a Bolt Model P400 343-in^3 gun (fig. 4) and a Bolt model S80 80-in^3 gun (fig. 5). An additional Bolt model 10B 1-in^3 gun was available but not fired. The water gun creates an energy pulse by rapidly moving a piston, ejecting water from the chamber area, and creating a cavity. This produces an implosion that sends a high-frequency energy pulse through the water. This energy pulse is relatively short, bubble free, and has more high-frequency energy and less low-frequency energy than the air gun (Hutchinson, 1984).

Two water guns were individually fired during testing—the 343-in^3 water gun and the 80-in^3 water gun. Water guns were secured on a hoist to a floating raft, which was secured to a tagline affixed to each side of the canal wall (fig. 6). The water guns were lowered to 12.5 ft below water surface, approximately half the canal depth.

Figure 4. Water gun with piston size of 343 cubic inches.

Figure 5. Water gun with piston size of 80 cubic inches.

Figure 6. Water gun setup in canal 30 feet from canal wall (hydrophone cable extending from white pipe, borehole with geophone cable).

The 343-in^3 water gun was initially located 90 ft from the canal wall, greater than half the 167-ft width of the canal, and fired at 2,000 pounds per square inch (lb/in^2). Ten separate successful water gun firing datasets were collected at 90, 80, 70, 60, 50, 40, and 30 ft from the canal wall, thus generating 70 datasets in total. Data collection was stopped at 30 ft based on previous reports of hydrophones potentially being damaged at distances less than 30 ft (J. Gross, U.S. Geological Survey, oral commun., 2011).

The 80-in^3 water gun was then attached and lowered to approximately 12.5 ft below water surface. Ten successful water gun firing datasets were collected at 30, 40, and 50 ft away from the canal wall.

At the conclusion of successful data collection with the 343-in^3 and 80-in^3 guns collecting concurrent hydrophone and 3C (downhole and land) geophone data, surface P and S (4.5 Hz) surface geophones were installed approximately the same distance from the canal wall as the 5-ft borehole. Data were then collected with the 80-in^3 gun at 2,000 lb/in^2 with the water gun located 30 ft from the canal wall. Data for the water guns were collected at a 0.125-ms sampling interval for 8 s.

Barge Traffic Source

Potential background noise was recorded while 12 barges and several recreational boats passed through the canal during the period of the water gun testing. Water gun testing was suspended during boat traffic. These datasets were determined to be a better comparison than the planned collection of background barge traffic approximately 0.7 mile upstream at the existing USGS gaging station because of the identical layout of geophones and hydrophones and geologic conditions. Data for barge traffic were collected at either a 1-ms sampling interval for 60 s or at 16-ms intervals for 260 s (4.33 minutes). Some background noise records were also made without barge or boat traffic.

Industrial Background Source

Industrial-background seismic data were collected at the coal power plant approximately 1,000 ft downstream from the electric fish barrier. Seismic data were also collected while freight trains were passing near the electric fish barrier. A crushed rock and gravel operation immediately south of the coal power plant did not have a suitable location to locate geophones in relation to the canal and the primary seismic source (conveyor belt and crane loading of material onto barges), but the operational energy from the rock and gravel operation was considered approximately equal to the coal power plant source (based on conveyor belt and crane loading of similar material onto barges). A refinery located within the area of the electric fish barrier was determined to be located far enough away not to be a significant seismic source, based on personal observation.

Five 3C surface geophones were installed in a north-south line away from a potential seismic source—a conveyor belt approximately 50 ft from the canal wall and leading to a crane that loaded coal onto barges. The largest noise source was the coal hitting the barge container during loading. The closest geophone in the line was approximately 200 ft away from the location where barges are loaded (fig. 3). The five geophones were spaced every 30 ft and were anchored in loose granular coal. Continuous data were collected during the loading of coal to a barge. Data for energy transmitted by coal being loaded and (or) unloaded were collected at 16-ms (0.016-s) intervals for 260 s.

Seismic data were collected during the passing of freight trains (potential seismic sources) on site at the north end of the electric fish barrier. The 3C surface geophones were located in a 25-ft-square array with one geophone centrally located. Pointed tips of geophones (channel 2) were oriented north. The center of the square array was approximately 60 ft east from the canal wall and approximately 140 ft west of the edge of the railroad tracks (fig. 3). Data were recorded while seven freight trains passed near the electric fish barrier site. Data for freight train traffic were collected at 16-ms intervals for 260 s.

Results

Signals from seismic energy sources, including water gun firings, barge traffic, freight train traffic, and a coal-loading facility, were recorded by seismographs; datasets are cataloged in appendix 1. Raw digital data files are available at http://dx.doi.org/10.3133/ds938/. All values are in mV. Geophone data may be converted to ground motions (ground velocity) using the conversion factor of 0.698 Volt per inch per second (V/in/s). Hydrophone conversion from mVs to lb/in^2 are affected by an unknown error factor resulting from cable length and cable composition; therefore, hydrophone mV data should not be used in direct computation of lb/in^2.

Selected Data

All dataset files are available at http://dx.doi.org/10.3133/ds938/ and viewable with software that is capable of reading SEG-2 format available in U.S. Geological Survey Open-File Report 01–141 (Ellefsen, 2003). Other open-source software, such as Geopsy (available at http://www.geopsy.org/), are available to read SEG-2 formatted data. Selected data are documented below.

80-Cubic-Inch Water Gun at 50 Feet from the Canal Wall

Ten datasets were recorded when the 80-in^3 gun was fired at 2,000 lb/in^2 50 ft from the wall. Maximum signal from the surface 3C geophones at 5, 35, and 100 ft were 89, 45, and 12 mV, respectively. The maximum for the PVC pipe data was 86 mV. The hydrophone data maximum value was 89 mV.

Background Data

Barge datasets maximums for surface 3C geophones from 5, 35, and 100 ft were 4, 3, and 1 mV, respectively. Maximum data value for the PVC pipe ranged from less than 1 to more than 100 mV. Maximum data for the hydrophone streamer ranged from less than 1 to more than 100 mV.

Railroad noise near the fish barrier collected from passing freight trains approximately 140 ft distant from surface 3C geophones produced a maximum output of approximately 1 mV on October 20, 2011, and 2.5 mV (erroneous spikes on one geophone from 8.dat were not used) for data collected on November 1, 2011. No background hydrophone data were collected.

Signals recorded adjacent to the coal power plant with surface 3C geophones had a maximum value of 31 mV. Data were not recorded with hydrophones at this location.

Signal Saturation

During the processing and review of this dataset, it was determined that the seismic and pressure signals at close distances saturated the amplifiers and placed artificial limitations on the range resulting in clipping of signals recorded by the seismograph. Clipping occurred in signals received from geophones placed in the borehole that was 5 ft from the canal wall, the geophone located in the PVC tube mounted on the canal wall, and hydrophones. These data were not included. Data collected at 35 ft and further are unaffected for all datasets. A 90-mV signal response should be considered a minimum value for saturation and clipping to occur; data exceeding 90 mV should be examined for possible saturation and clipping.

Summary

The water gun is a potential method of controlling Asian carp within the Chicago Area Waterway System (CAWS), notably in the Chicago Sanitary and Ship Canal (CSSC) within the vicinity of the electric fish barrier. There is concern that energy released from water gun use may negatively affect the canal walls, structures, and (or) the equipment necessary to maintain the fish barrier. The potential effect of the use of a water gun on the canal wall and structures in the CSSC was assessed and compared to other existing background energy sources. To determine the relative energy outputs of the water gun operation relative to other energy sources, such as barge traffic and industrial-background noise, relative energy outputs were determined from each source. Two water guns (80- and 343- in^3 pistons) were fired at various locations within the canal. Data were collected from hydrophones in the canal. Data were also collected from geophones at the canal wall/water interface, on land, and in boreholes at the approximate elevation of the water gun, at 5, 35, and 100 ft from the canal wall. In general, energy produced by barge and railroad sources was less than energy created by the water gun. Coal-loading operations approximately 200 ft (or further) from geophones produced maximum energy levels that were approximately four (or less) times less energy than water gun operations.

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Keevin, T.M., and Hempen, G.L., 1997, The environmental effects of underwater explosions with methods to mitigate impacts: St. Louis, Missouri, U.S. Army Corps of Engineers.

Appendix 1. Seismic Data, Data-collection Equipment, and Borehole Characteristics for the Chicago Sanitary and Ship Canal (CSSC)

Seismic Data

Seismic data in this report are online in the SEG-2 format at http://dx.doi.org/10.3133/ds938/. Seismic data can be accessed through standard geophysical software that is capable of reading SEG-2 files. Software capable of reading SEG-2 format is available and documented in U.S. Geological Survey (USGS) Open-File Report 01–141 (Ellefsen, 2003) available at http://pubs.usgs.gov/of/2003/ofr-03-141/. Other open-source software, such as Geopsy (available at http://www.geopsy.org/), are available to read SEG-2 formatted data. The data files are arranged in the following folders:

- September 27_2011th–CSSC
- September28_2011–CSSC
- September 29_2011–CSSC
- Oct 20_2011–Coal Plant
- Nov 1_2011– Rail Road

Equipment

Data were collected using Geometrics Geode seismographs and collected on personal computers using Single Geode Operating System (SGOS) and Multiple Geode Operating System (MGOS) software.

Three types of three-component (3C) sensors were deployed: RTClark 10-Hz surface geophones, RTClark 10-Hz downhole geophones, and Mark Products L15B 4.5-Hz surface geophones. Each of the three components corresponds to channels as shown below:

10–Hz surface geophones

- Channel 1: transverse component
- Channel 2: longitudinal component
- Channel 3: vertical component

10–Hz borehole geophones

- Channel 1: transverse component
- Channel 2: transverse component
- Channel 3: vertical component

Orientation of transverse components within the boreholes was unknown, due to rotation of the geophones before they were attached to the borehole wall. The orientation of components of the tube geophone on the canal wall was established through tap tests, as described below.

4.5–Hz surface geophones

- Channel 1: vertical component
- Channel 2: longitudinal component (referred to as H-1)
- Channel 3: transverse component (referred to as H-2)

Borehole Characteristics

Borehole 1: 5 ft from the canal wall

- Depth – 29.5 feet (ft) below ground surface
- Diameter – 3 inches (in.)
- Casing – 10 ft
- Stickup – 0.1 ft above ground surface

Borehole 2: 35 ft from the canal wall

- Depth – 39.4 ft below ground surface
- Diameter – 4 in.
- Casing – 20 ft
- Stickup – 1.2 ft above ground surface

Borehole 3: 100 ft from the canal wall

- Depth – 35.0 ft below ground surface
- Diameter – 4 in.
- Casing – 15 ft

- Stickup – 0.24 ft above ground surface

Chicago Sanitary and Ship Canal Data Sensor Configurations and Shot Information (343–cubic–inch water gun)—September 27, 2011

Files 86.dat through 125.dat

[PVC, polyvinyl chloride; ft, feet; lb/in^2, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22	MP-24-3 hydrophone (4 ft below water surface)

File	Water gun pressure (lb/in^2) or noise source	Gun distance from canal wall (ft)
86.dat–87.dat	Background noise	
88.dat	1,000	90
89.da –90.dat	Background noise	
91.dat	1,000	90
92.dat	Barge	
93.dat	Background noise	
94.dat–96.dat	1,500	90
97.dat	Background noise	
98.dat–99.dat	1,500	90
100.dat–103.dat	2,000	
104.dat–108.dat	1,000	30
109.dat–113.dat	1,500	30
114.dat	Background noise	
115.dat–119.dat	2,000	30
120.dat–123.dat	500	30
124.dat–125.dat	Barges	

Files 127.dat through 180.dat (new sensor configuration)

[ft, feet; PVC, polyvinyl chloride; lb/in^2, pounds per square inch; ch, channel]

Seismograph channels	Sensor location
1–3	Borehole 1, 3C deep 3C geophone
4–6	Hydrophone streamer (3, 11, and 19 ft below water surface)
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, 3C shallow geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall (tap test indicates ch 19 perpendicular to canal, ch 20 parallel to canal, ch 21 vertical)
22	MP-24-3 hydrophone (4 ft below water surface)

File	Water gun pressure (lb/in^2) or noise source	Gun distance from canal wall (ft)
127.dat–136.dat	2000	90
137.dat–145.dat	2000	80
146.dat	Background noise	
147.dat	Sailboat	
148.dat	2000	80
149.dat	2000	70
150.dat–152.dat	Background noise	
153.dat–161.dat	2000	70
162.dat–164.dat	Background noise	
165.dat	Barge (with crane)	
166.dat	Background noise	
167.dat	2 barges side-to-side	
168.dat–177.dat	2000	60
178.dat	Background noise	
179.dat	Background noise	
180.dat	Barge (very slow)	

Chicago Sanitary and Ship Canal Data Sensor Configurations and Shot Information (343-cubic-inch water gun)—September 28, 2011

Files 181.dat through 234.dat

[ft, feet; lb/in^2, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, 3C deep 3C geophone
4–6	Hydrophone streamer (3, 11, and 19 ft below water surface)
7–9	Borehole 2, deep 3C geophone
10	MP-24-3 hydrophone (11.5 ft below water surface)
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22	MP-24-3 hydrophone (4 ft below water surface)

File	Water gun pressure (lb/in^2) or noise source	Gun distance from canal wall (ft)
181.dat–185.dat	Background noise	
186.dat–191.dat	2,000	50
192.dat	Background noise	
193.dat–194.dat	2,000	50
195.dat	Background noise	
196.dat–197.dat	2,000	50
198.dat	2,000	40
199.dat	Background noise	
200.dat–208.dat	2,000	40
209.dat–221.dat	Barge (220.dat barge closest)	
222.dat	Background noise	
223.dat–231.dat	2,000	30
232.dat	Pleasure boat	
233.dat	Background noise	
234.dat	2.000	30

Files 235.dat through 291.dat

[PVC, polyvinyl chloride; ft, feet; psi, pounds per square inch; mV, millivolt; s, second]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, surface 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, surface 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, surface 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)

File	Water gun pressure (psi) or noise source	Gun distance from canal wall (ft)
235.dat	Background noise	
236.dat–245.dat	2,000	30
246.dat–256.dat	2,000	40
257.dat–268.dat	2,000	50
269.dat	Barge	
270.dat	Double barge (side-to-side)	
271.dat	Double barge with cavitation (peak 89 mV at 230 to 240 s)	
272.dat–278.dat	Barge backing up	
279.dat	2 large pleasure boats	

Chicago Sanitary and Ship Canal Data Sensor Configurations and Shot Information (80-cubic-inch water gun)—September 28, 2011

[psi, pounds per square inch; ft, feet]

File	Water gun pressure (psi) or noise source (raindrop impacts visible on all three surface geophones)	Gun distance from canal wall (ft)
280.dat	Background noise	
281.dat–285.dat	2,000	30
286.dat	Background noise	
287.dat–291.dat	2,000	30

Chicago Sanitary and Ship Canal Data Sensor Configurations and Shot Information (80-cubic-inch water gun)—September 29, 2011

Files 2097.dat through 2135.dat

[PVC, polyvinyl chloride; ft, feet; psi, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)
25–27	Surface 3C geophone near Borehole 1
28–30	Surface 3C geophone near Borehole 2
31–33	Surface 3C geophone near Borehole 3

File	Water gun pressure (psi) or noise source	Gun distance from canal wall (ft)
2097.dat–2100.dat	Background noise	
2101.dat –2103.dat	2,000	30
2104.dat	Background noise	
2105.dat–2111.dat	2,000	30
2112.dat	Background noise	
2113.dat	2,000	30
2114.dat–2123.dat	2,000	40
2124.dat	Barge	
2125.dat–2134.dat	2,000	50
2135.dat	Barge	

Files 2136.dat through 2138.dat

[PVC, polyvinyl chloride; ft, feet; NIU, Northern Illinois University; vert., vertical; Hz, hertz]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and19 ft below water surface)
25	NIU vert. geophone at Borehole 3 (Mark Prod. L10–B 8.25 Hz)

File	Water gun pressure (psi) or noise source	Gun distance from canal wall (ft)
2136.dat	Background noise	
2137.dat –2138.dat	2,000	30

Files 2139.dat through 2142.dat

[PVC, polyvinyl chloride; ft, feet; NIU, Northern Illinois University; horiz., horizontal; Hz, hertz; psi, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)
25	NIU horiz. geophone at Borehole 3 (Mark Prod. L28LBH 4.5 Hz)

File	Water gun pressure (psi) or noise source	Gun distance from canal wall (ft)
2139.dat –2142.dat	2000	30

Files 2143.dat through 2144.dat

[PVC, polyvinyl chloride; ft, feet; NIU, Northern Illinois University; vert., vertical; Hz, hertz; psi, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)
25	NIU vert. geophone “A1” at Borehole 3 (Mark Prod. L40A3 50 Hz)

File	Water gun pressure (psi) or noise source	Gun distance from canal wall (ft)
2143.dat –2144.dat	2000	30

Files 2145.dat through 2146.dat

[PVC, polyvinyl chloride; ft, feet; NIU, Northern Illinois University; vert. comp., vertical component; Hz, hertz; psi, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)
25	NIU 3C “A”, vert. comp., at Borehole 3 (Mark Prod. L15B 4.5 Hz)

Files 2147.dat through 2148.dat

[PVC, polyvinyl chloride; ft, feet; NIU, Northern Illinois University; comp., component; Hz, hertz; psi, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)
25	NIU 3C "A", H-1 comp., at Borehole 3 (Mark Prod. L15B 4.5 Hz)

File	Water gun pressure (psi) or noise source	Gun distance from canal wall (ft)
2147.dat–2148.dat	2,000	30

Files 2149.dat through 2150.dat

[PVC, polyvinyl chloride; ft, feet; NIU, Northern Illinois University; comp., component; Hz, hertz; psi, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)
25	NIU 3C, H-2 comp., at Borehole 3 (Mark Prod. L15B 4.5 Hz)

File	Shot size (psi) or noise source	Gun distance from canal wall (ft)
2149.dat–2150.dat	2,000	30

Files 2151.dat through 2152.dat

[PVC, polyvinyl chloride; ft, feet; NIU, Northern Illinois University; vert. comp., vertical component; Hz, hertz; psi, pounds per square inch]

Seismograph Channels	Sensor Location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)
25	NIU, vert. comp. “#10”, next to Borehole 2

File	Shot size (psi) or noise source	Gun distance from canal wall (ft)
2151.dat –2152.dat	2,000	30

Files 2153.dat through 2155.dat

[PVC, polyvinyl chloride; ft, feet; NIU, Northern Illinois University; vert, comp., vertical component; Hz, hertz; psi, pounds per square inch]

Seismograph channels	Sensor location
1–3	Borehole 1, deep 3C geophone
4–6	Borehole 1, shallow 3C geophone
7–9	Borehole 2, deep 3C geophone
10–12	Borehole 2, shallow 3C geophone
13–15	Borehole 3, deep 3C geophone
16–18	Borehole 3, shallow 3C geophone
19–21	3C geophone in PVC on wall
22–24	Hydrophone streamer (3, 11, and 19 ft below water surface)
25	NIU, vert. comp. “#9”, next to Borehole 2

File	Water gun pressure (psi) or noise source	Gun distance from canal wall (ft)
2153.dat	2,000	30
2154.dat	2,000	30
2155.dat	Background noise	

Coal Facility—October 20, 2011

All data were collected with a Geometrics Geode seismograph with SGOS running on either NIU's Xplore tablet computer or a USGS Dell laptop computer. Geophones were deployed along a north-south line with 30-ft spacing. The line of geophones was approximately 50 ft west of the CSSC and 200 ft north of barge coal-loading operations. Railroad tracks bordered the opposite (east) side of the canal. Channel order on the 3C geophones was always vertical, H-1(EW) and H-2 (NS). The pointed side of each geophone was oriented north.

Files 1.dat through 7.dat

[Hz, hertz]

Seismograph channels	Sensor location
1–3	Southernmost 3C geophone (10 Hz)
4–6	Next 3C geophone to the north (10 Hz)
7–9	Next 3C geophone to the north (10 Hz)
10–12	Next 3C geophone to the north (10 Hz)
13–15	Northernmost 3C geophone (10 Hz)

File	Event
1.dat	Background noise
2.dat	Coal loading
3.dat	Coal loading
4.dat	Train
5.dat	Train and coal loading
6.dat	2 trains
7.dat	Coal loading

Files 8.dat through 13.dat (All 3C geophones refer to the 10-Hz geophones, unless otherwise specified)

[Hz, hertz; NIU, Northern Illinois University; vert. comp., vertical component]

Seismograph channels	Sensor location
1–3	Southernmost 3C geophone (10 Hz)
6	NIU horizontal geophone, oriented north-south (no number)
7	NIU horizontal geophone, oriented east-west (#4)
8	NIU high-frequency vertical geophone (#17)
9	Low-frequency vertical geophone (#11)
10–12	NIU 3C, vert. comp. (#8) (Mark Prod. L15B 4.5 Hz): ch 10 H-2 (west), ch 11 V, ch 12 H-1 (north)
13–15	Northernmost 3C geophone (10 Hz)

Railroad, Barge, and Vehicle Traffic

Railroad Traffic at the Electric Barrier (October 20 and November 1, 2011)

On October 20, 2011, and November 1, 2011, background noise was collected near the electric fish barrier at Lemont, Illinois. A 25-ft-long square array was constructed approximately 200 ft north of the northern end of the electric fish barrier and approximately 60 ft east of the CSSC and 140 ft west of the north-south-trending railroad tracks. The array consisted of four 3C surface geophones at each corner of the square and one 3C geophone located in the center of the square. The center of the square array was approximately 50 ft east from the east edge of the CSSC and approximately 135 ft west of the west edge of the pair of north-south railroad tracks. Two datasets of freight trains passing were collected on October 20, and seven datasets of freight trains passing were collected on November 1, 2011. The 3C geophones were all oriented north. Data were collected at 16-ms intervals for 260 s.

Files 14.dat through 19.dat (October 20, 2011)

Seismograph channels	Sensor location
1–3	Surface 3C geophone, southwest corner
4–6	Surface geophone, southeast corner
7–9	Surface geophone, northeast corner
10–12	Surface geophone, northwest corner
13–15	Surface 3C geophone, center of square array

File	Event
14.dat	Wind and background noise
15.dat	Freight train (from north)
16.dat	Barge tug
17.dat	Barge and truck on road east of array
18.dat	Background noise
19.dat	Freight train (from south, fast)

Files 3.dat through 9.dat—November 1, 2011

Seismograph channels	Sensor location
1–3	Surface 3C geophone, southwest corner
4–6	Surface 3C geophone, southeast corner
7–9	Surface 3C geophone, northeast corner
10–12	Surface 3C geophone, northwest corner
13–15	Surface 3C geophone, center of square array

File	Number of Train Engines
3.dat	3
4.dat	4
5.dat	3
6.dat	3
7.dat	Unknown - Collected data after train engines had passed
8.dat	2
9.dat	2

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