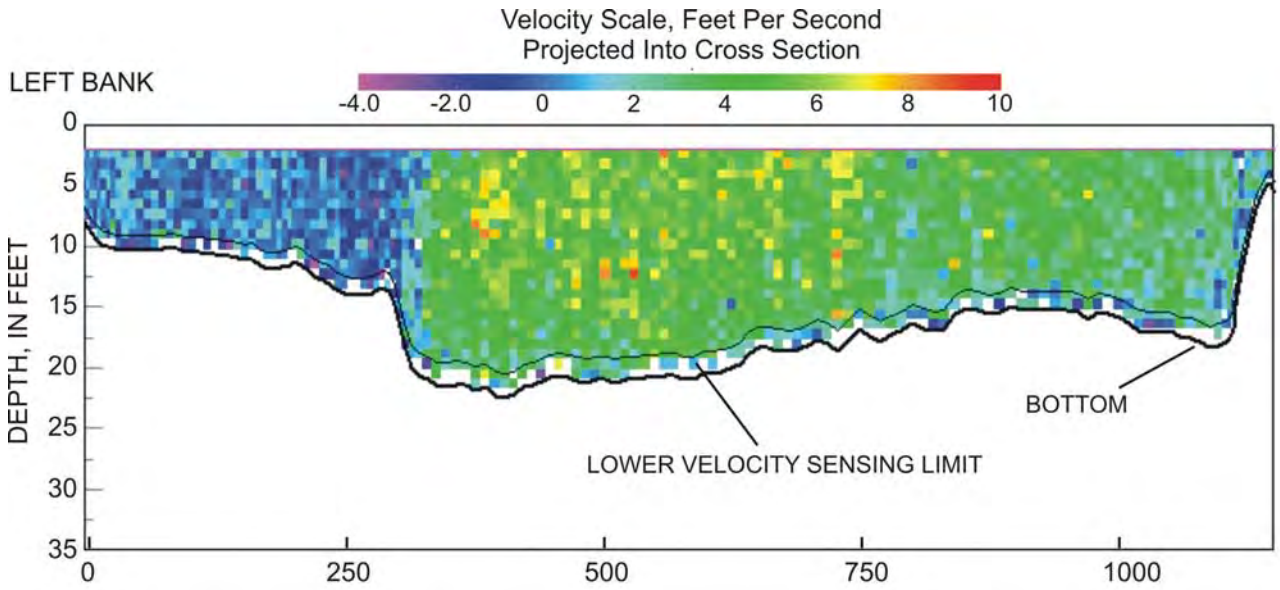
Assessment of Shallow-Water Habitat Availability in Modified Dike Structures, Lower Missouri River, 2004

By Robert B. Jacobson, Caroline M. Elliott, and Harold E. Johnson, III



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Contents

Contents iii
Figures iii
Tables iv
Conversion Factors and Datums v
Abstract 1
Introduction 1
  Shallow-water Habitat and the Lower Missouri River Ecosystem 1
  Purpose and Scope 2
Approach and Methods 4
  Hydrology 4
  Hydroacoustic Mapping 4
  Data Reduction and Maps 6
    Bathymetry 6
    Substrate 7
    Velocity 7
    Estimation of Elevation Quantiles 7
Results 9
  Grand River Confluence Reach 9
  Glasgow Reach 10
  Lamine River Confluence Reach 10
Discussion 11
  Reference Flow Regime 11
  Elevation Control 11
  Water-Surface Elevation Quantiles and Habitat Extent 12
  Monitoring Time Scales 16
  Evaluating Depth and Velocity 16
Summary and Conclusions 16
References Cited 17

Figures

1. Map showing location of shallow-water habitat evaluation sites and streamgages 3
2. Hydrographs showing A. instantaneous discharges during 2004 surveys, and B. daily mean discharges from pre-modification surveys to post-modification 5
3. Graph showing example of differences in elevations calculated by two methods 12
4. Graphs showing hypsometric curves, pre- and post-modification, and range of elevations corresponding to shallow-water habitat depth criteria 14-15

Tables

1. Locations, survey dates, and notes on dike modifications in this report 2
2. Construction reference plane elevations, flow quantiles, and water-surface elevations at streamflow gaging stations 8
3. Pre- and post-modification survey dates and prevailing discharges 9
4. Comparison of discharge and stages quantiles using historical and modeled hydrologic time series 11
5. Estimated shallow-water habitat acreage for surveyed wing dike fields 15

Conversion Factors and Datums

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)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Altitude, as used in this report, refers to distance above the vertical datum.

Conventional Units: Scientists writing about U.S. rivers face a dilemma because the scientific community expects adherence to the System International (S.I.) units of measure whereas managers and the public relate almost exclusively to conventional and customary units of measure. Because of the importance of communicating results to stakeholders in the Missouri River basin, this report presents discharges in customarily used units of cubic feet per second, and river locations in terms of river miles. Depths, other horizontal dimensions, and velocities, however, are presented in customary units with parenthetical S.I. equivalents. The conversion table above can be used to convert between additional units. River miles begin at 0 at the junction of the Missouri River with the Mississippi River at St. Louis, and increase in the upstream direction. Reference to left (L) and right (R) bank locations relate to direction while facing downstream.

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By Robert B. Jacobson, Caroline M. Elliott, and Harold E. Johnson

Abstract

This study documented the effects of wing-dike notching on the availability of shallow water habitat in the Lower Missouri River. Five wing dikes were surveyed in late May 2004 after they were notched in early May as part of shallow-water habitat (SWH) rehabilitation activities undertaken by the U.S. Army Corps of Engineers. Surveys included high-resolution hydroacoustic depth, velocity, and substrate mapping. Relations of bottom elevations within the wing dike fields to index discharges and water-surface elevations indicate that little habitat meeting the SWH definition was created immediately following notching. This result is not unexpected, as significant geomorphic adjustment may require large flow events. Depth, velocity, and substrate measurements in the post-rehabilitation time period provide baseline data for monitoring ongoing changes. Differences in elevation and substrate were noted at all sites. Most dike fields showed substantial aggradation and replacement of mud substrate with sandier sediment, although the changes did not result in increased availability of SWH at the index discharge. It is not known how much of the elevation and substrate changes can be attributed directly to notching and how much would result from normal sediment transport variation.

Introduction

During 2004, the U.S. Army Corps of Engineers accelerated channel morphology modifications on the Lower Missouri River to increase the availability of shallow-water habitat (SWH, operationally defined as water 0-5 feet deep and 0-2 feet/second current velocity). This work was carried out in coordination with the U.S. Fish and Wildlife Service in order to meet objectives outlined in the Missouri River Biological Opinion (U.S. Fish and Wildlife Service, 2000; 2003). Rehabilitation activities included construction of side-channel chutes, notching wing dikes, increasing channel top-width, and notching bank revetments.

Performance evaluations of the physical aspects of this activity rely on pre- and post-construction surveys to determine how rehabilitation has affected the availability and diversity of habitat. Habitat assessment should consider at least the main characteristics of physical aquatic habitat: depth, velocity, and substrate. In order to assess geomorphic adjustments to modification, surveys also should include accurate assessments of bottom topography.

Shallow-water Habitat and the Lower Missouri River Ecosystem

The Lower Missouri River channel morphology has been substantially changed compared to the historical condition. Clearing of woody debris and stabilization of the Missouri River began in the early 1800's to improve conditions for steamboat navigation. Most of the river's permanent engineering structures, however, are the direct result of the Missouri River Bank Stabilization and Navigation Project, part of the Pick-Sloan Act of 1944 (Ferrell, 1996). Wing dikes and revetments have stabilized the riverbanks, and narrowed and focused the thalweg to maintain a self-dredging navigation channel from St. Louis, Missouri, 735 miles (1,200 km [kilometers]) upstream to Sioux City, Iowa. The result has been to create a narrow, swift, and deep channel from what was historically a shallow, shifting, braided river. Riverine habitat loss has been estimated as much as 100,000 acres (about 400 km^2 [square kilometers]; Funk and Robinson, 1974; Hesse and Sheets, 1993). Recognition of the scope of habitat loss has increased interest in rehabilitating parts of the Missouri River (Latka and others, 1993).

Ecologists generally accept the premise that physical habitat is a central factor in organizing aquatic ecosystems (Gorman and Karr, 1978; Schlosser, 1987; Power and others, 1988; Jeffries and Mills, 1990). Factors

other than physical habitat (for example, nutrients, energy, competition with invasive species, or contaminants) are also potentially important in determining ecosystem functions. However, most management emphasis on the Lower Missouri River (St. Louis, Missouri to Yankton, South Dakota; fig. 1) has been on physical habitat because of the magnitude of change and the direct connection of physical habitat to management actions (U.S. Fish and Wildlife Service, 2000; 2003; U.S. Army Corps of Engineers, 2004).

Evaluations of physical habitat rehabilitation on the Lower Missouri River mainstem currently concentrate on a single measure of physical habitat: areas of shallow and slow water, known as shallow-water habitat (SWH). It is widely accepted that survival and growth of young fish are associated with the availability of shallow water with slow velocity (see for example, Scheidegger and Bain, 1995; Bowen and others, 1998; Freeman and others, 2001). The exact bounds of depth and velocity that are optimal as an index for habitat evaluation, however, vary among studies. Bowen and others (2003), for example, use water less than 3.2 ft (1 m) deep and current velocities less than 0.8 ft/s (0.25 m/s). On the Missouri River, habitat analysis has concentrated on a definition of SWH as 0-5 ft (0-1.5 m) and 0-2 ft/s (0-0.6 m/s) (U.S. Fish and Wildlife Service, 2000) . Although complex interactions among water properties, substrate, topography, and biota cannot be fully described by this one habitat class, it serves as a useful index of functional habitat.

As part of efforts to mitigate habitat losses and to recover native species, the U.S. Army Corps of Engineers embarked during Spring 2004 on a program to create 1,200 acres (486 hectares) of new SWH by early Summer. The dominant measures to create more SWH in the 2004 program were notching of wing dikes and banks, and construction of side-channel chutes. Dike modifications documented in this report were completed in May 2004; dike notches represent a relatively small part of the total SWH effort.

Purpose and Scope

Our analysis focuses on five wing-dikes that were notched during early May 2004, and for which we had pre-modification habitat surveys that were collected for other purposes (table 1, fig. 1). The objective of the study is to evaluate the effects of modifications on SWH availability, and to provide baseline information to use for evaluation of long-term habitat changes resulting from ongoing geomorphic adjustment.

Table 1. Locations and notes on surveyed, modified structures. Notch dimensions are widths; notches were excavated nominally to 4 ft below the construction reference plane (75% exceedance water surface). Structures were modified during April and May, 2004.

[GPS, global positioning system; RTK, real-time kinematic]

River Mile	Structure Number	Early May 2004 Modification	Pre-Modification Survey Date	Post-Modification Survey Date	Survey Notes
250.1	D-260.3	50 ft notch	3/7/2002	5/17/2004	Grand River reach. Depth, velocity, substrate; differential GPS, indirect elevation control; 15 m transects.
222.5	D-233.6	50 ft notch	7/11/2003	5/25/2004	Glasgow River reach. Depth, elevation, velocity, substrate; RTK GPS elevation control; 40 m transects
222.3	D-233.4	50 ft notch	7/11/2003	5/25/2004	Glasgow River reach. Depth, elevation, velocity, substrate; RTK GPS elevation control; 40 and 20 m transects
203.3	R-212.3	Enlarge existing notch	10/16/2003	5/25/2004	Lamine River reach. Depth, elevation, velocity, substrate; RTK GPS elevation control; irregular survey within revetment area; 20 m transects outside
201.1	D-209.6	50 ft notch	10/10/2003	5/25/2004	Lamine River reach. Depth, elevation, velocity, substrate; RTK GPS elevation control; 20 m transects

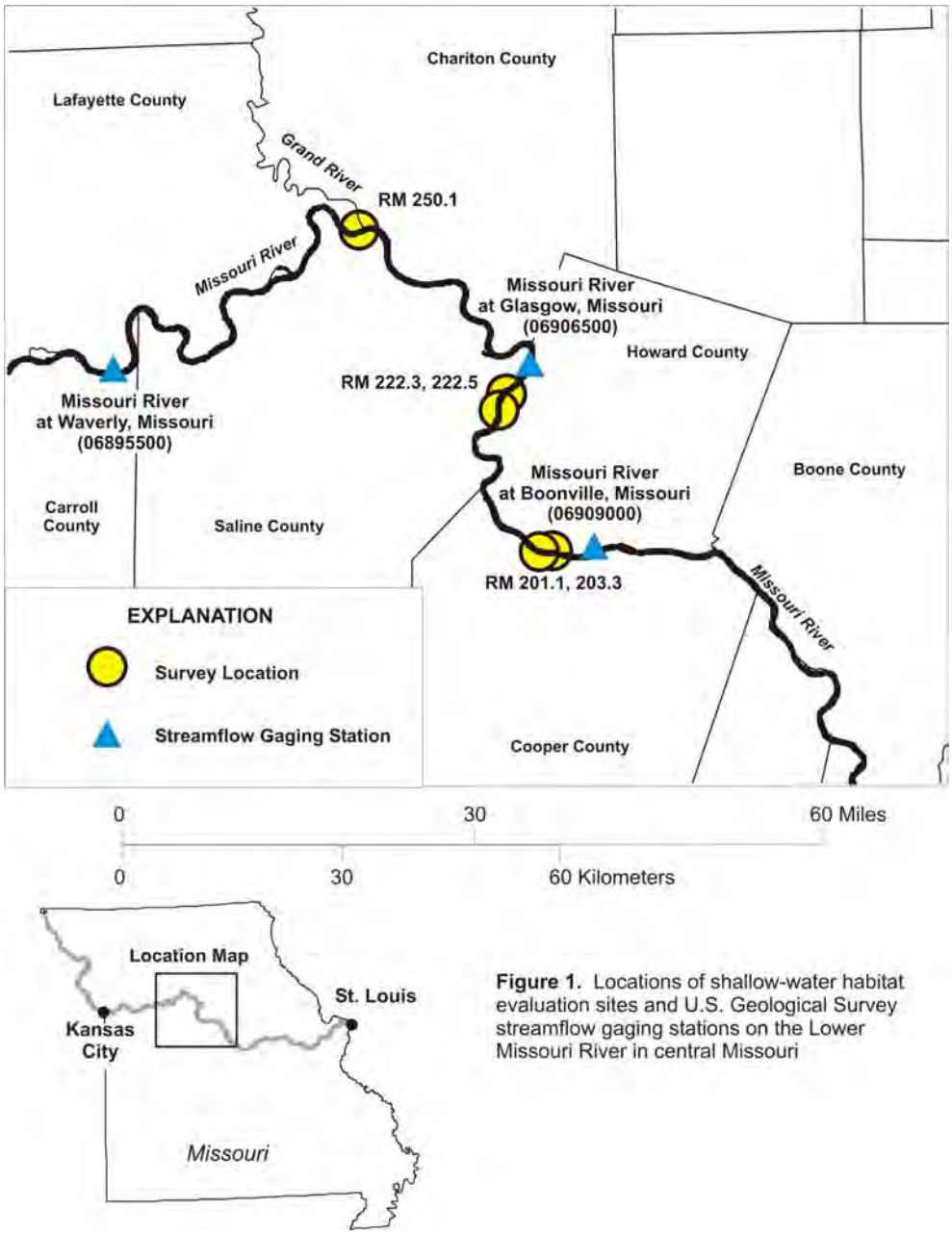

Figure 1. Locations of shallow-water habitat evaluation sites and U.S. Geological Survey streamflow gaging stations on the Lower Missouri River in central Missouri

Our objective was to develop depth, velocity, substrate, and elevation maps of pre- and post-modification conditions. To assess habitat availability for the July 15 – August 15 index time frame identified in the 2003 Biological Opinion (U.S. Fish and Wildlife Service, 2003) it would have been preferable to assess habitat near the median flow of the index period during relatively steady discharge. Because of a deadline to demonstrate attainment of SWH acreage before July 2, 2004, mapping had to be completed and documented during a relatively short time frame (May 14, 2004 – June 4, 2004). Consequently, it was not possible to match the median flow or assure steady discharges (fig. 2). Therefore, depths and velocities reported here (and to a lesser extent, substrate) will not be strictly comparable to the index time frame. Because elevation changes are less dynamic, elevations may be more comparable to those expected during median discharges of the index time period. Similarly, it would have been preferred to match pre- and post-modification surveys to the same index discharges. However, as the pre-modification surveys were completed at various discharges before this study was anticipated, and given the highly dynamic discharge during the post-modification surveys, this also was not possible.

Maps included all wetted area of at least 1 ft (0.3 m) depth from just upstream of the modified wing dike, extending through the downstream area of influence of the wing dike, and from the near shoreline to the navigation

line (or thalweg) as shown on USACE navigation charts. The downstream extent of wing dike influence was delineated by the adjacent, downstream wing-dike, or by the downstream limit of sandbar that was geometrically related to the dike. For quantitative comparison of habitat between pre- and post-modification surveys, we defined a Habitat Inventory Area (HIA), a rectangular box representative of the dike influenced area and common to both surveys.

Approach and Methods

The general approach to evaluating effects of modification was to map habitats in notched wing-dike areas using hydroacoustic instruments that were georeferenced using high-precision real-time kinematic global positioning system (RTK GPS). Maps will allow for characterization of habitat and provide baseline information for monitoring and assessment of changes. English and Systeme Internationale (SI) measurement units are emphasized in this report to facilitate communications with managers, stakeholders, and the public. English units are the customarily used in management decisions, legal discussions, and by the public. Readers are referred to the conversion table to convert between units.

Hydrology

The 2003 Biological Opinion (U.S. Fish and Wildlife Service, 2003) establishes July 15 – August 15 as an index time frame for evaluation of SWH. We calculated median, 75%, and25% exceedance discharges (that is, daily mean discharges equaled or exceeded 50%, 75%, and 25% of the time) for the index time frame using 1967-2003 historical records at U.S. Geological Survey (USGS) streamgaging stations at Waverly, Missouri (06895500) and Boonville, Missouri (06909000). The record at Glasgow is not of sufficient length to calculate quantiles reliably. The 1967-2003 timeframe covers the post-dam-closure hydrology of the Lower Missouri River, but quantiles calculated from the historical record may be biased – over the long term – by high flows of the 1990's. For reference, 75%, 50%, and 25% flow exceedances at Boonville, Missouri, for the index period are shown on figure 2A.

Hydroacoustic Mapping

The effects of modification were addressed with hydroacoustic mapping on the dates shown in table 1. Hydroacoustic mapping used standard U.S. Geological Survey, Columbia Environmental Research Center (CERC) procedures (Elliott and others, 2004; Jacobson and others, 2002). Digital copies of navigation charts were used as base maps for transect design and real-time navigation using HyPack ® (Coastal Oceanographics, Middlefield, Connecticut) navigation software. Sampling transects were constructed to cover areas adjacent to and downstream of notched dikes, and extending at least to the navigation line. Sampling transects were generated at 33 ft (10 m) and 66 ft (20 m) spacing and oriented generally perpendicular to the channel thalweg. The transect spacing was selected to provide sufficient spatial coverage for creating continuous surface maps of depth, velocity, and substrate data given usual scales of variation of these characteristics. Transects were ended laterally when the depth became too shallow for the boat, at approximately 1 ft (0.30 m) depth.

All data were georeferenced in the field by a 12-channel RTK-GPS system, except for the pre-modification survey at river mile (RM) 250.1. The RM 250.1 survey was conducted in March 2002 using differential GPS (DGPS). The RTK-GPS produces positional data with horizontal and vertical accuracies to within 0.1 ft (0.02 m). The DGPS gives x and y positions to approximately 3 ft (1 m) accuracy; elevation accuracy of DGPS is not sufficient for mapping elevations (the March 2002 survey at RM 250.1 was intended only for depths). All GPS data were collected at 200 millisecond (ms) intervals, resulting in positions approximately every 1.0 ft (0.3 m) along each transect at typical boat speeds of 2 – 4 knots (1-2 meters per second, m/s) during data collection. Boat speeds were typically maintained at 5 knots or less.

Bathymetric data were collected with an Hydrotrac ® echo sounder (Odom Hydrographic Systems, Inc, Baton Rouge, LA) equipped with a 208 kHz (kilohertz), 8^{o} transducer mounted over-the-side of the boat, directly below the GPS antenna. The echo sounder was calibrated by bar check to account for boat draft, blanking distance (distance just below transducer for which echo returns are not possible), and environmental conditions that could affect the speed of sound in water. Pitch and roll were not compensated; however, the boat was not operated under

conditions with significant waves. The precision of the echosounder data is 0.1 ft (0.03 m). Bar check results indicate that, under favorable bottom conditions, the depth and elevation accuracy is approximately 0.23 ft (0.07 m).

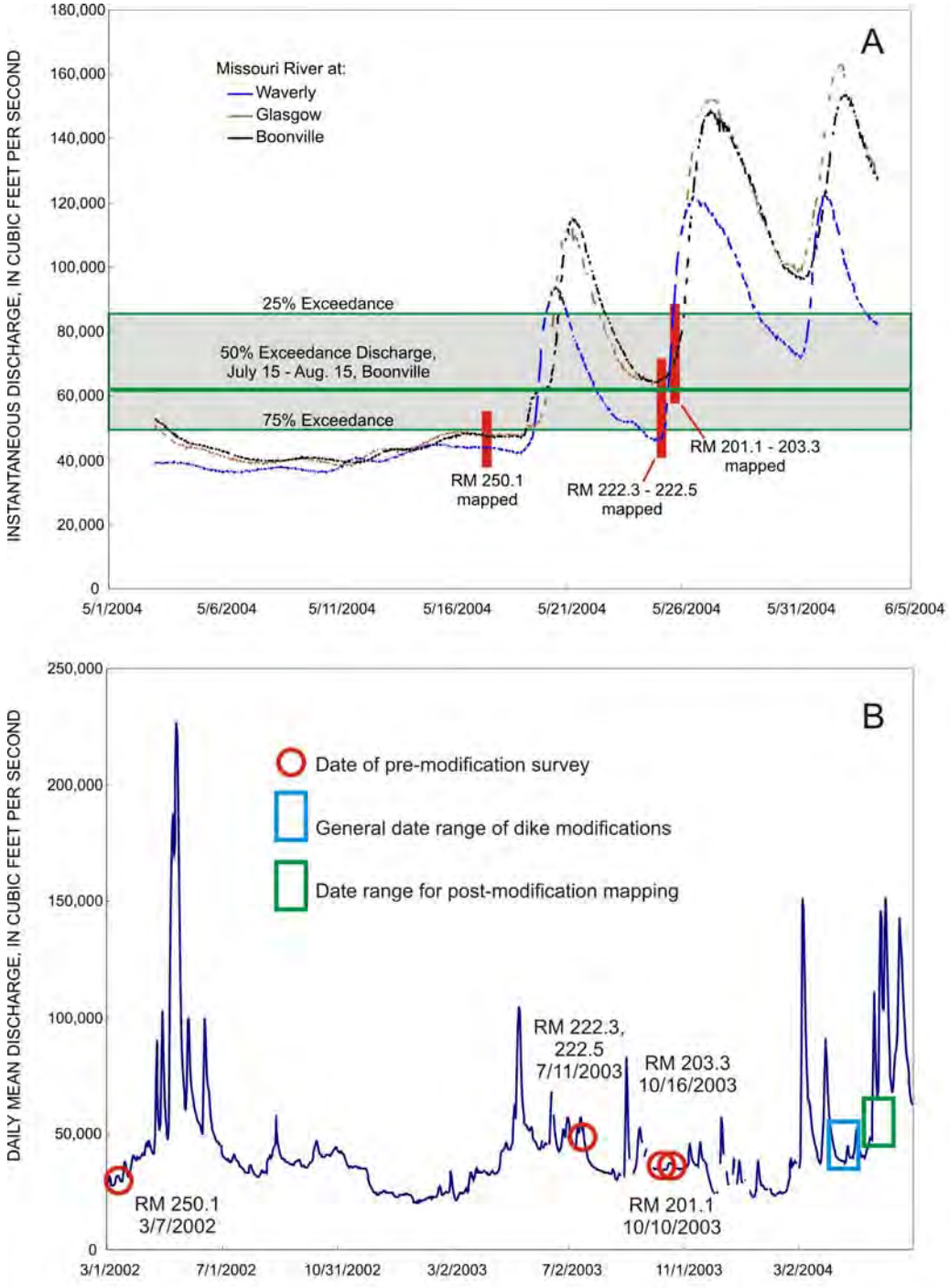

Figure 2. Hydrographs showing hydrologic context of wing-dike modifications and measurements. A. Hydrographs showing instantaneous discharges at three local U.S. Geological Survey streamflow gaging stations, and median and interquartile range of post-regulation July 15 - August 15 discharges at Boonville, Missouri. Red bars indicate timing of habitat evaluation mapping. B. Hydrograph of daily mean discharges at Boonville, Missouri showing dates of pre- and post-modification surveys and timing of dike modifications.

Bed material was classified into substrate classes using a RoxAnn ® system (Stenmar Marine Microsystems, Aberdeen, Scotland), which uses the transducer output from the echosounder. The RoxAnn analyzes the shape of the acoustic signal returned from the river bottom to calculate two parameters related to roughness and hardness (e1 and e2) (see, for example, Rukavina, 1997). Depth, bed-material classification, and GPS positions were logged into standardized HyPack files.

Velocity data were collected with a Workhorse Rio Grande Model® 600 kHz or 1200 kHz acoustic Doppler current profiler (ADCP, RD Instruments, San Diego, California), depending on water depth conditions. These data also were georeferenced with RTK-GPS data, but were logged on a separate laptop computer running the WinRiver ADCP acquisition program. The ADCP was set up to collect 3-dimensional water velocity data in 0.8 - 1.1 ft (0.25 - 0.35-m) depth intervals (bins) from the surface to the bottom following generally accepted setup and operation procedures (Morlock, 1996). A column of bins (called an ensemble) was collected nominally every 2.5 s (seconds), resulting in an ensemble spacing that varied from approximately 8 – 33 ft (2.5 – 10 m) at typical boat speeds. For ADCP data collection, boat speeds were maintained below 5 knots, resulting in a maximum ensemble spacing of about 12 ft (3.8 m). The ADCP was internally calibrated for measured water temperature and compensates automatically for pitch and roll.

Data Reduction and Maps

Hydroacoustic data were reduced and compiled into maps of bathymetry (elevation and depth), substrate, and velocity. For purposes of comparison with previous data and analysis, the data were gridded to produce continuous surface maps.

Bathymetry

Water depth data were edited using a routine included with HyPack to remove spurious reflections from water-column turbulence, vegetation, or fish and to correct for places where bottom conditions prevented a good digitization of the echo. Elevations were obtained by calculating the orthometric height of the RTK antenna using the Geoid99 model and the NAVD88 vertical datum. Elevations of the channel bottom were then calculated by subtracting the distance from the antenna to the water surface, the calibrated draft of the echosounder transducer, and depth recorded by the echosounder from the antenna elevation. Following editing for accuracy and content, the datasets were exported from HyPack as comma-delimited files containing data of Universal Transverse Mercator (UTM) northing and easting, depth, elevation, and substrate for each data point.

A Perl software script (Practical Extraction and Report Language, ActiveState Corporation, Vancouver, British Columbia), was used to edit and format the comma-delimited files and prepare them for grid creation. Surfaces were interpolated using Surfer 7 ® (Golden Software, Inc., Golden Colorado) by kriging with a linear variogram model and zero anisotropy. An eight quadrant search was used against the 33 or 66 ft (10 or 20-meter) spacing of transects. Spurious data points were eliminated from consideration and the output grid resolution was set to 16 ft (5-meter). A masking file was then used to clip the interpolated grid to the extent of the input data set. The Surfer 7 grids were exported as ASCII files and then added to an ArcView ® (version 3.3, Environmental Systems Research Institute, Inc, Redlands, California) project as a table. Each table was added to a view as a point event theme and converted to a 16 ft (5-m) grid.

For the RM 250.1 site, channel elevations were calculated indirectly by reference to an estimated water-surface elevation. Offsets of water-surface elevations from the construction reference plane (CRP) were calculated for the streamgages at Waverly and Glasgow on the day of survey. The CRP is an imaginary sloping plane that approximates the water-surface elevation of average low flows (nominally 75% flow exceedance; U.S. Army Corps of Engineers, 2003). The slope of the CRP is constant between gages so CRP elevation can be interpolated at any distance along the river.

The offset (del-CRP) was apportioned along the channel by linearly prorating between the upstream (Waverly) offset and the downstream (Glasgow) offset. The prorated offset was added to the CRP elevation at RM 250.1, and converted from NGVD29 vertical datum to NAVD88. The del-CRP reference was also used to estimate stages associated with flow exceedances at each site; the inherent errors in this method are discussed in a later section.

Substrate

Raw substrate roughness (e1) and hardness (e2) values were exported from HyPack. A Perl software script was then used to transform the raw e1 and e2 values by taking the square root and multiplying by 100, resulting in integer data with near-normal probability distributions. The roughness (e_1) and hardness (e_2) values were imported into Surfer 7 for surface interpolation using 8-quadrant kriging.. These files were also clipped with a mask file, and imported as event themes and converted to 5-m grids in ArcView.

Grids for roughness, hardness, and depth were classified into four substrate classes using a multivariate unsupervised classification routine in ArcInfo ® (version 8.3, Environmental Systems Research Institute, Inc., Redlands, California) (Elliott and others, 2004). Unsupervised classification was validated with a supervised classification based on ground-truth points encompassing the range of substrate types in the Lower Missouri River. Ground truth and interpretation of the unsupervised classification were developed through collection of sediment samples at shallow depths, and side-scan sonar imagery for areas of greater depth, in previous studies (Elliott and others, 2004).

Velocity

ADCP data were exported from WinRiver ® (RD Instruments, San Diego, California) as ASCII-formatted files and reformatted with a Perl script for import into ArcView. The velocity magnitude, horizontal velocity direction, vertical velocity component, and position (easting, northing, and depth) were extracted for each individual bin during this reformatting step. A Perl software script also calculated the depth-average velocity for each ensemble (vertical collection of data). These data subsequently were imported into ArcView for 2D visualization. Mean water-column velocity magnitude data were imported to Surfer 7, which interpolated data by kriging into 16.4-ft (5-m) intervals. The data were clipped with a mask file, imported in ArcView as an event theme and grids of mean velocity magnitude were produced with a 16-ft (5-m) cell size.

Estimation of Elevation Quantiles

A specific challenge in evaluating aquatic habitat is comparing sites, or a single site over time, in terms of the same hydrologic condition. Changes in habitat availability as a result of hydrologic variation (over a time frame where changes in topography due to sediment transport can be neglected) can be evaluated by one of three general methods:

1. Selection of an index discharge and measurement of habitat characteristics only during that discharge, plus/minus a nominal amount of variation as a practicality.
2. Measurement over a range of discharge to construct discharge-habitat area curves. Once discharge-habitat curves are constructed, habitat can be compared at any discharge or flow duration interpolated from the curve.
3. Hydraulic modeling to generate discharge-habitat curves.

In this study we attempted the first approach, but encountered practical difficulties because of the dynamic hydrologic situation over the compressed time frame of the study, and because the pre-modification surveys were prepared for other purposes before the need for the comparison study was appreciated.

All approaches share the practical need of estimating stage-discharge relations at the site of interest. Unless they can be developed by onsite survey, they will have to be estimated by relation to the CRP. For example, flow quantiles for the index period at each gage can be associated with a del-CRP at the gage, and the del-CRP can be apportioned along the river to the site of interest. Added to the CRP at the site (from CRP tables by river mile), the del-CRP for the flow quantiles provides an estimate of stages associated with specific discharges. The weaknesses in this method are that a) it assumes the CRP accurately reflects a constant flow duration datum along the river and b) it implicitly assumes an identical stage-discharge relation at every point along the river. While these assumptions may be sufficient for some bathymetric and engineering applications, the inherent errors in assumptions and interpolations may be substantial compared to the scale of habitat formation at rehabilitation sites, especially over short time intervals.

Table 2 shows flow quantiles for the index period at Waverly and Boonville gages, del-CRP values, and apportioned del-CRP values and associated water-surface elevations at the five wing dikes. The implications of using this method to estimate elevation quantiles are discussed in a later section.

Table 2. Construction Reference Plane (CRP) elevations, flow quantiles, and water-surface elevation quantiles for US Geological Survey streamflow gaging stations and wing-dike modification sites.

[ft, feet; cfs, cubic feet per second; NGVD29, National Geodetic Vertical Datum of 1929; NAVD88, North American Vertical Datum of 1988; Q_{25}, flow equaled or exceeded 25% of the time, 25% flow exceedance; Q_{50}, 50% flow exceedance; Q_{75}, 75% flow exceedance]

						July 15 - August 15					
		NGVD29		NAVD88		Discharge, in cfs			Water Surface Elevation, NAVD88 ft		
Streamgage	River Mile	Gage Datum, ft	CRP	Gage Datum, ft	CRP, ft	Q_{25}	Q_{50}	Q_{75}	Q_{25}	Q_{50}	Q_{75}
Boonville	197.1	565.42	574.30	565.52	574.40	86,500	65,500	49,700	580.22	577.29	574.86
	201.1		579.35		579.49				585.27	582.37	579.96
	203.3		579.52		579.68				585.44	582.56	580.16
	222.3		595.51		595.60				601.20	598.46	596.16
	222.5		595.68		595.77				601.37	598.63	596.33
Glasgow	226.3	586.49	598.88	586.58	598.97						
	250.1		619.41		619.49				624.85	622.30	620.15
Waverly	293.4	646.00	656.90	646.34	657.24	78,200	60,900	47,500	661.03	658.11	655.68

Results

Five wing dike areas previously surveyed for other purposes were resurveyed May 17th and May 25th, 2004 (table 3). The results are grouped by geographic location, and discussed from upstream to downstream in the following sections.

Table 3. Survey dates and prevailing discharges.
[cfs, cubic feet per second]

		Pre-Modification		Post-Modification	
Structure	River Mile	Date	Daily Mean Boonville Discharge, cfs	Date	Daily Mean Boonville Discharge, cfs*
D-209.6	201.1	10/10/2003	34,400	5/25/2004	69,200
R-212.3	203.3	10/16/2003	37,400	5/25/2004	69,200
D-233.4	222.3	7/11/2003	53,700	5/25/2004	69,200
D-233.6	222.5	7/11/2003	53,700	5/25/2004	69,200
D-260.3	250.1	3/7/2002	27,700	5/17/2004	47,600

* Discharge at Boonville 5/25/2004 varied 66,000 – 73,000 cfs during survey

Grand River Confluence Reach

One dike was mapped on the river-right bank, just across from the Grand River confluence. Maps and cross sections from spur dike D-260.3 are found in the appendix. This dike was initially surveyed in March 2002 as part of a flathead catfish (*Pylodictis olivaris*) habitat-use study. Daily mean discharge at the time of the 2002 survey was 27,700 cfs at the Boonville gage, 25,600 cfs at the Glasgow gage, and 25,200 cfs at the Waverly gage. At this discharge, access to potential shallow-water areas was limited.

The 2002 topography of the D-260.3 dike field was dominated by a very large scour hole and an extensive sandbar downstream and toward the channel from the scour hole (fig. A.1). The sandbar was incompletely mapped in 2002. Depth maps from the two surveys document erosion of the bar and shifting of the thalweg from left bank to right between the two survey dates (figs. A.1 and A.5). Velocities within the HIA vary 0-5 ft/s (0-1.5 m/s); just within the "velocity shadow" of the wing dike, velocities are uniformly low for both surveys, mostly less than 1 ft/s (0.3 m/s) (figs. A.4, A.8). Between the two surveys, the high-velocity core in the main channel shifted substantially from the left bank to much closer to D-260.3. ADCP cross sections also document that flow velocity behind the wing dikes was uniformly low (figs. A.9, A.10; cross sections in appendix are shown facing downstream, velocities projected into the plane of the section; negative velocities are upstream-directed, indicating recirculating flows). The 2004 ADCP cross section shows a small core of higher velocity that appears to relate to the notch location. The area of muddy sediment in the middle of the scour in 2002 had diminished in size by the time of the 2004 survey (fig. A.6). The scour now has sandy and rocky sediment in the center with muddy sediment extending downstream over the bar.

Elevation change at this site from 2002 to 2004 was dramatic. Shifting of the thalweg in the main channel from the left bank to the right bank (movement of the cross-over downstream) was associated with aggradation of as much as 10 ft (3.0 m) on the left channel margin and as much as 13 ft (4.0 m) in the center of the scour associated with D-260.3 (fig. A.11). The new thalweg position showed matching degradation of 6-8 ft (1.8-2.4 m), and erosion of the sandbar in the Grand River mouth resulted in local degradation of 14-16 ft (4.3-4.9 m) along the left bank. Shifting of the thalweg also was associated with lateral erosion of the sandbar downstream of D-260.3 and probably as much as 13 ft (4.0 m) of deposition in the D-260.3 scour.

Glasgow Reach

Two adjacent spur dikes were mapped in the Glasgow Reach. Maps and cross sections from spur dikes D-233.4 and D-233.6 are found in the appendix. These dikes were initially surveyed in July 2003 as part of a pallid sturgeon (*Scaphirhynchus albus*) habitat-use study. Daily mean discharge during the 2003 survey was 53,700 cfs at the Boonville streamgage and 55,800 cfs at the Glasgow streamgage . This discharge was sufficient for good coverage of most shallow-water areas.

Dike fields D-233.4 and D-233.6 were treated as one mapped area because of their adjacency, but they are topographically very dissimilar (figs. A.12, A.16). The upstream dike has a persistent and prominent scour hole at the tip and just upstream whereas the downstream dike has a much more subdued scour at the tip. The upstream dike lacks a deep scour adjacent to the bank while the downstream dike has a very prominent scour adjacent to the bank. Substantial bar areas are developed downstream of both dikes. Velocities in both 2003 and 2004 surveys were dominantly less than 2.5 ft/s (0-0.76 m/s) behind the wing dikes (figs. A.15, A.19). A core of higher velocity (2.5 – 3.5 ft/s; 0.76 – 1.1 m/s) is apparent in the 2004 survey downstream of the notch in D-233.4; the core of high velocity may relate to the presence of the notch or the slightly higher discharge in 2004. Substrate in both dike fields in 2004 was substantially coarser than in 2003 (figs. A.13, A.17). It is not clear how much of the replacement of mud with sandier substrate results from differences in discharge alone and how much can be attributed to notching. A mud-covered bar detached from the shore in the D-233.4 field may have resulted from flow through the notch, resulting in a coarser channel between the bar and shore. This muddy patch does not conform to topographic contours, however. Elevation change maps document general aggradation of 0-3 ft (0-1 m) in both dike fields with some discrete areas of degradation 0-4 ft (0-1.2 m).

Lamine River Confluence Reach

Two modified wing dikes were mapped in the Lamine River Reach. Maps and cross sections from spur dike D-209.6 and trailing dike R-212.3 are found in the appendix. These dikes were initially surveyed in October 2003 to construct a 2-dimensional hydraulic model of the Lamine River junction with the Missouri River. Daily mean discharges were 34,400 – 37,400 cfs (cubic feet per second) on the Boonville gage during the pre-modification survey. Spatial coverage was limited due to low water so some of the area downstream of D-209.6 was not mapped in 2003.

Trailing dike R-212.3 is an extension of revetment parallel to the shore. The aquatic area landward of the dike is extremely narrow but surprisingly deep (fig. A.25, A.29). A small scour hole existed near its upstream end in 2003, and a deep scour existed off the tip. In 2004, depths were more variable, and the 2004 elevation map confirms two prominent bar-like features. Velocities were uniformly low during the 2003 survey and remained less than 2.5 ft/s during the 2004 survey (figs. A.28, A.32). ADCP cross sections were not collected because of the narrow area and orientation of the area behind the dike. Substrate in 2003 was dominated by mud except for some sandy sediment in deep portion just upstream of the downstream L-head dike (fig. A.26). In 2004, the upstream area on the landward side of the dike was notably sandier than it was in 2003 (fig. A.30). The elevation change map documents areas of 2-4 ft (0.6 – 1.2 m) aggradation behind the dike (fig. A.33). Conclusions about performance of this dike area should take into account the difficulty in mapping, gridding, and contouring data in the narrow area which may limit the resolution of the data.

Dike D-209.6 had relatively deep scours adjacent to the bank and off the tip in October 2003 (fig. A.34). A steep-sided sandbar existed downstream with a shallow secondary channel adjacent to the bank. These features persisted after the notching, but lack of coverage in 2003 limits analysis of change. Velocities in 2003 and 2004 were dominantly less than 4 ft/s in the HIA; differences between main channel and wing-dike velocities were greater at the higher discharges in 2004. Velocities in the protected area downstream of the wing dike were 0-2 ft/s (0-0.61 m/s). A small area of velocity maximum in 2004 near the junction of the dike with the bank appears to indicate the effect of the notch (fig. A.41). This effect is confirmed in the ADCP cross sections (figs. A.42, A.43). The 2004 cross section velocity profiles show greater diversity of velocity patterns within the dike field. A smaller area of mud substrate was mapped in the complex in 2004 than in 2003 (figs. A.35, A.39); it is not known whether this amount of change could

have resulted from the notching or would be expected normally with discharge variation. The change map documents areas of as much as 3 ft (1 m) of aggradation in the parts of the wing-dike complex covered by maps from both surveys (fig. A.44).

Discussion

The following sections address challenges of inventorying and assessing changes in physical habitat in rehabilitation projects. Five issues identified are: determining reference flow regime, establishing elevation control, relating elevations in projects to flow duration, determining relevant monitoring time horizons, and evaluating velocities.

Reference Flow Regime

The 2003 Missouri River Biological Opinion (U.S. Fish and Wildlife Service, 2003) charges the Corps to evaluate SWH during July 15 to August 15. The implication is that a particular flow exceedance or range of flows should be used to determine how much SWH exists during that time period. The specific flow exceedance and hydrologic time series for calculating flow duration were not specified. In absence of guidance, we have assumed median flow for the July 15 – August 15 index period. The median flow (and other flow exceedances) however will vary depending on the hydrologic time series used to calculate them.

For this study we used the historical, post-regulation 1967 – 2003 record for streamgages at Waverly and Boonville. An alternative would be to use output of the Corps' Daily Routing Model (DRM, U.S. Army Corps of Engineers, 1998) which synthesizes a long-term daily flow dataset for a subset of streamgages (including Boonville). The DRM provides 100 years of daily data 1898 - 1998, thereby modeling reservoir management scenarios over a wider range of hydroclimatic variability than available with historical data alone. The DRM flow exceedances are uniformly lower than the recent historical record because the DRM includes very dry years during the 1930's. Table 4 shows differences in flow and water-surface elevation quantiles for the index period comparing the historical record to the DRM MCP300, a specific flow regime scenario used to model the current (May 2004) water control plan. The differences in reference flow regime result in 0.7 – 1.6 ft of differences stage at the streamgage. This amount of vertical variation in reference water-surface elevation could substantially alter SWH habitat inventories in some areas. Hence, future habitat assessment should specify the reference flow regime.

Table 4. Comparison of discharge and stage quantiles using historical 1967 - 2003 record and MCP300 1898 - 1998 daily routing model record (DRM), at Boonville, Missouri.

[cfs, cubic feet per second; ft, feet; Q_{25}, flow equaled or exceeded 25% of the time, 25% flow exceedance; Q_{50}, 50% flow exceedance; Q_{75}, 75% flow exceedance]

	July 15 - August 15					
	Discharge, in cfs			Water Surface Elevation, ft		
Gage	Q_{25}	Q_{50}	Q_{75}	Q_{25}	Q_{50}	Q_{75}
Historical 1967 - 2003	86,500	65,500	49,700	580.22	577.29	574.86
MCP300[1] 1898 - 1998	81,200	55,300	40,200	579.51	575.74	573.31
Historical minus DRM	5,300	10,200	9,500	0.71	1.55	1.56

[1] U.S. Army Corps of Engineers daily routing model scenario used to model the current (May 2004) water control plan.

Elevation Control

The initial survey of dike D-260.3 at RM 250.1 lacked RTK-GPS elevation control and therefore water-surface elevations had to be estimated by reference to CRP (see Approach and Methods section). To estimate errors inherent with this method and the implications of comparing del-CRP elevation control with

RTK-GPS, we calculated elevations at dikes D-209.6 (RM 201.1) and D-233.4/D-233.6 (RM 222.3-222.5) using both methods, and assessed differences by subtracting RTK-GPS gridded elevation dataset from the del-CRP elevation dataset (fig. 3). The subtraction involved exactly co-registered datasets, but because of spatial averaging involved with the gridding process, the errors should be viewed as spatially averaged errors. The mean difference for RM 201.1 was 1.8 ft (0.55 m, standard deviation, 0.5 ft, 0.16 m) and the mean difference for RM 222.3-222.5 was – 0.43 ft (-0.13 m, standard deviation, 0.06 ft, 0.02 m).

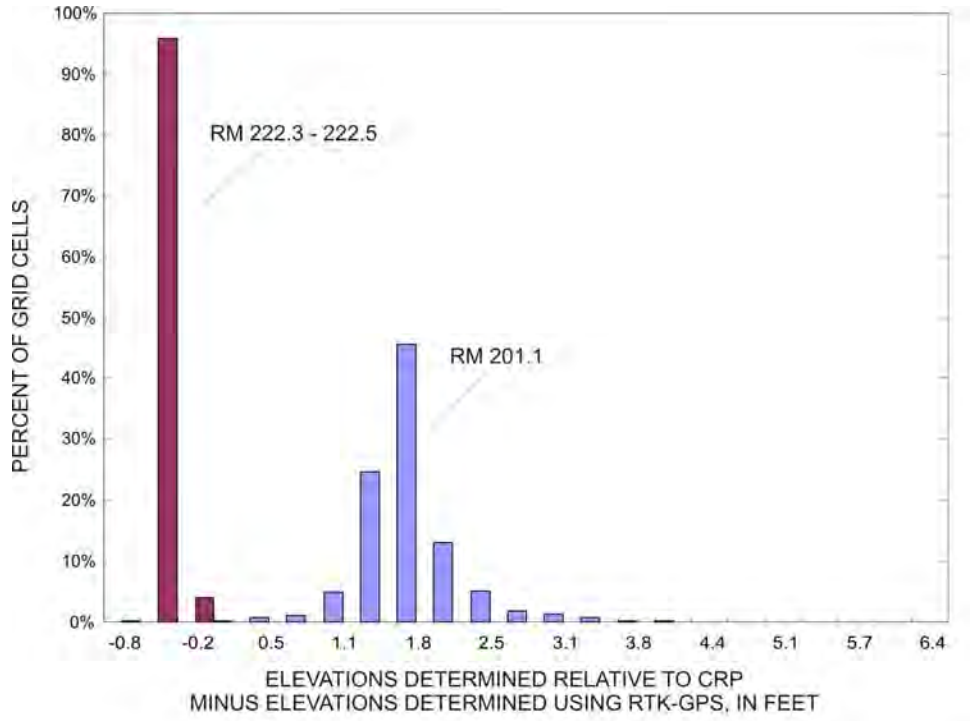

Figure 3. Histogram showing distribution of elevation errors calculated as del-CRP method minus RTK-GPS method for gridded elevation datasets of surveys on 5/25/2004.

Elevation accuracy of RTK-GPS in our method (combined ellipsoid height, echo-sounder, and random error) is estimated at ± 0.22 ft (0.07 m). Therefore, these comparisons indicate mainly errors associated with the del-CRP method. As discussed above, using offsets from CRP at streamgage sites for elevation control relies on assumptions that the CRP represents constant flow duration along the river and that stage-discharge relations along the channel do not vary significantly. The second assumption is particularly problematic for assessment of rehabilitation projects since a fundamental result of the rehabilitation activity is to change the local stage-discharge relation. An additional technical problem is estimating the del-CRP during a day when discharge varies substantially. This analysis suggests that elevation calculations using del-CRP may differ by as much as -0.6 to + 2.0 ft (-0.2 to +0.6 m) from actual elevations, which could be significant in assessing habitat acreage. Improved precision could be obtained by calculating and comparing elevations consistently using only one of the two methods, but as indicated by figure 3, the precision of the del-CRP method also varies among sites. The RTK-GPS method would consistently improve precision and accuracy.

Water-Surface Elevation Quantiles and Habitat Extent

Flow exceedance during the index time period needs to be estimated and translated to water-surface elevation at each rehabilitation site in order to assess sites on a constant hydrologic basis. Options

for doing this involve either developing independent stage-discharge relations at each site or using offsets from CRP. If offsets from CRP are used, all of the assumptions and potential errors discussed above with respect to estimating elevation control also would apply to estimation of water-surface quantiles.

Figure 4 shows the cumulative areal distribution of elevations (hypsometric curve) for the Habitat Inventory Areas of dikes at RM 201.1, RM 222.3-222.5, and RM 250.1 (the trailing dike at RM 203.3 was omitted from the analysis because of its small size). The median and 75% flow exceedance quantiles are indicated, with shaded bands showing the water-surface elevation minus 5 feet (1.5 m, the depth criterion for SWH).

The hypsometric curve is a fundamental descriptor of the habitat availability at a site. Rehabilitation activities presumably will serve to move the curves upward toward water-surface elevations associated with the index period. Flatter hypsometric curves in the 0-5 ft (0-1.5 m) range for the index flows will maximize SWH area. Gently sloping hypsometric curves indicate more elevation and depth diversity than flat curves.

On the hypsometric curves, the difference between the maximum bottom elevation and the index water-surface elevation indicates the area of emergent terrestrial habitat with the surveyed area. In all cases in this report, emergent terrestrial area is zero because discharges during the surveys were not sufficient to map higher surfaces on the margins of the dike fields; such areas are not extensive and were not directly affected by the modifications. The difference between the maximum bottom elevation and median water-surface elevation minus five feet indicates the area meeting the SWH depth criteria. By using a more liberal criterion and including all water-surface elevations between the 50% and 75% flow exceedances minus 5 ft, somewhat larger acreages are calculated (table 5). In all cases in this sample, however, the acreages are small, indicating that little SWH area exists at target flow elevations. Errors in estimating water-surface elevations for 75% and 50% flow exceedances on the order of -0.6 to +2.0 ft (-0.2 m to + 0.6 m) could significantly affect estimates of area meeting the SWH depth criterion.

Acreage calculations from hypsometric curves also can be influenced by the total area that can be surveyed at a given discharge. Our RM 201.1 (May 17, 2004) survey was at relatively low discharge and therefore bar areas attached to the right bank were not included. Surveys at higher discharge (like the May 25, 2004 surveys) include some additional area at higher elevations and may therefore measure additional habitat conforming to SWH index discharges, if higher elevation areas exist. Even for the low water survey at RM 250.1 on May 17, 2004, however, all the area that would be expected to be affected directly by recent dike notching was included in the survey. Nevertheless, these results emphasize that to map elevations conforming to SWH criteria at index discharges requires mapping at discharges somewhat higher than the index so all the potential habitat acreage can be traversed by the boat. Alternatively, combined boat and terrestrial surveys could be used to assure that all potential habitat elevations are mapped.

Hypsometric curves for pre- and post-modification surveys indicate geomorphic changes in the dike fields, and gains or losses in SWH for the index discharges (fig. 4). Comparison of hypsometric curves for two surveys is complicated by the fact that water level differences between the surveys may dictate that different total areas are surveyed. The hypsometric curves in figure 4 are calculated on the same HIA areal basis, but some of the area under water in 2004 was above water and not mappable in the pre-modification surveys. For the RM 201.1 dike, the hypsometric curves support the conclusion that there was net loss of areas at low elevations from October 10, 2003 to May 25, 2004. Lower water during the pre-modification survey prevents any conclusions about gain or loss of areas corresponding to the SWH depth criterion. For the RM 233.4 – 233.6 dikes, the pre-modification survey is very similar to post-modification up to approximately 593 ft; in this case as well, lower water level during the pre-modification survey mitigates against strong conclusions about gains or losses of SWH. At RM 250.1, loss of area less than 598 ft elevation and gain in area greater than 602 ft elevation is evident. However, these measured changes are below elevations that would be effective in producing SWH.

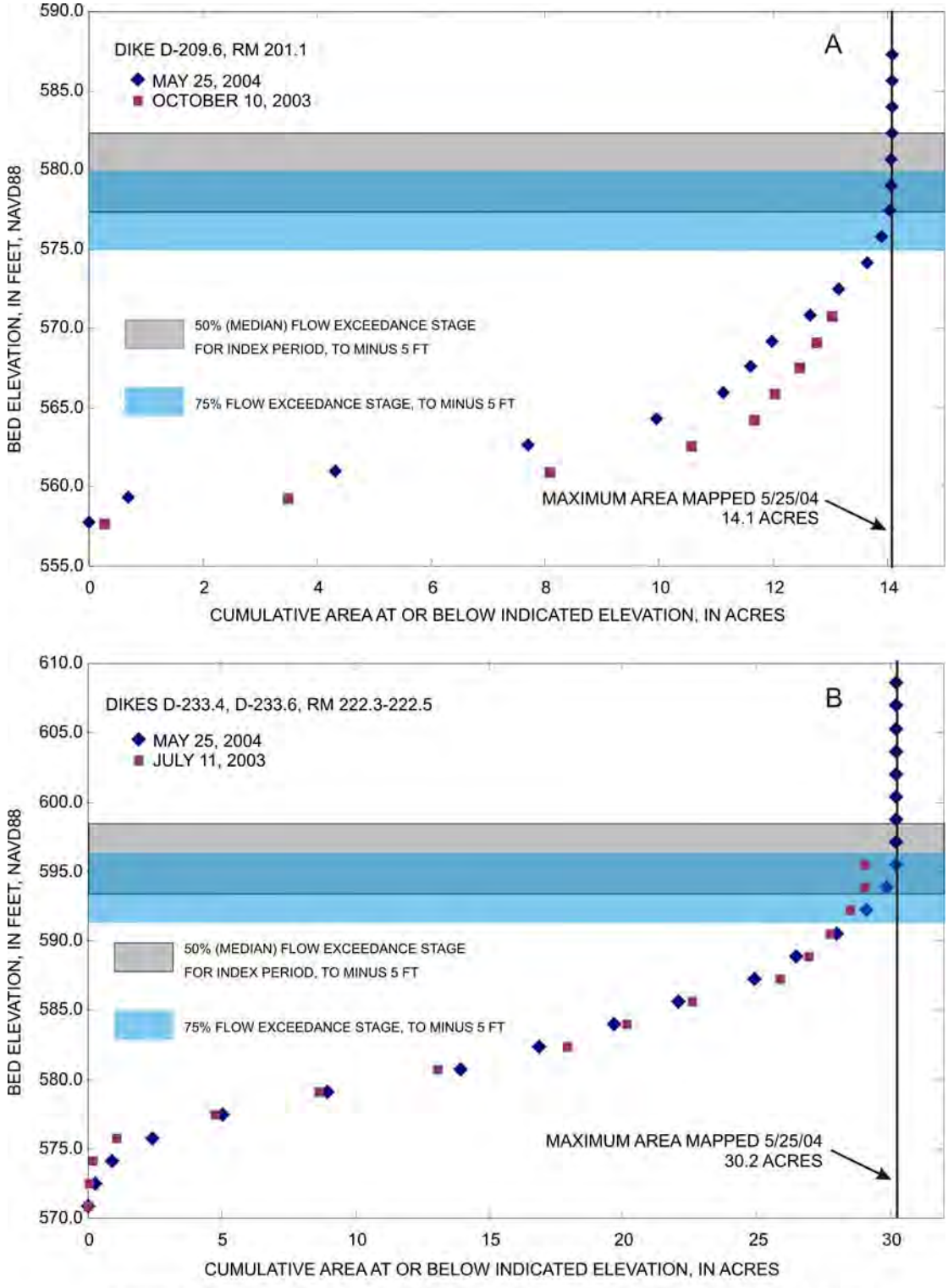

Figure 4. Hypsometric curves and estimated stages for discharge quantiles for four notched wing dikes, pre- and post-modification surveys. A. Dike near Lamine River junction. B. Combined adjacent dikes near Glasgow, Missouri

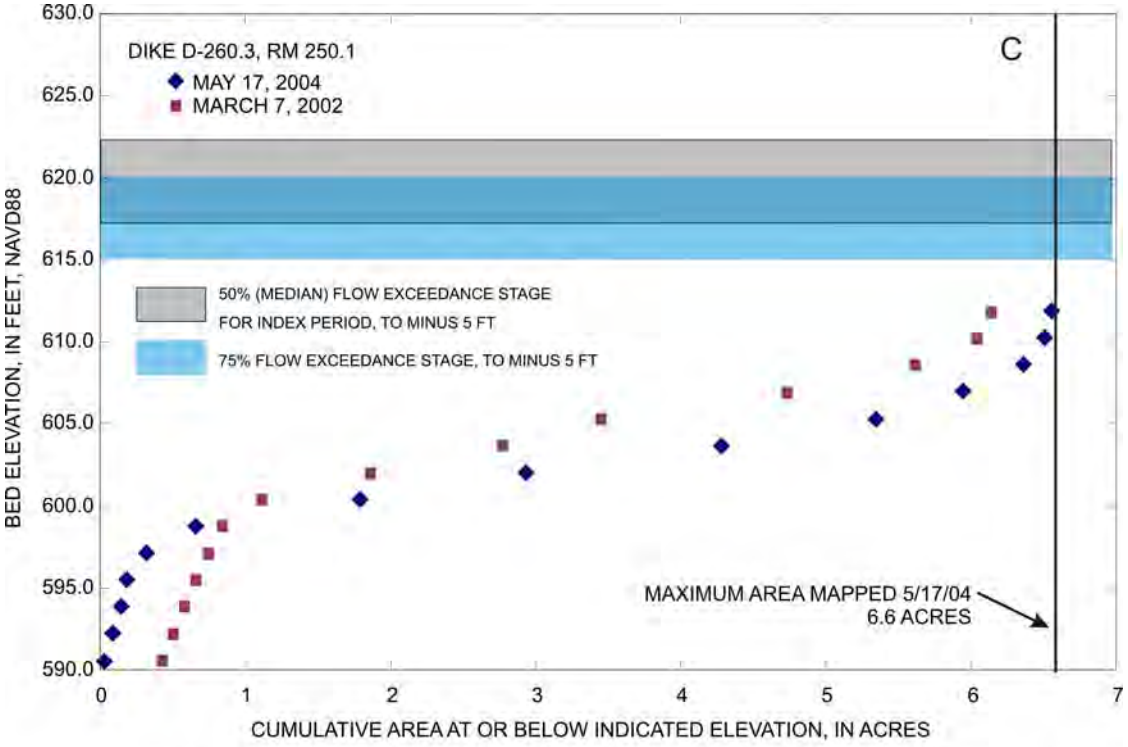

Figure 4 (cont.). Hypsometric curves and estimated stages for discharge quantiles for four notched wing dikes, pre- and post-modification surveys. C. Dike across from Grand River junction.

Table 5. Estimated SWH availability calculated from surveys on indicated dates, using 50% and 50-75% flow exceedances calculated for Boonville streamflow gaging station, historical record, 1967 - 2003. Availability estimate uses only depth criteria for SWH.

[ft, feet]

			50% exceedance minus 5 ft	50 to 75% exceedance minus 5 ft
Structure	River Mile	Date	Availability, in acres	
D-209.6	201.1	5/25/2004	0.03	0.29
D-233.4-233.6	222.3-222.5	5/25/2004	0.39	1.73[1]
D-260.3	250.1	5/17/2004	0.00	0.00[2]

[1] Combination of two dikes; average acreage per notched dike is 0.86 acres.
[2] Low water on the date of survey prevented survey of some areas on the margins of the dike field. These areas may provide some habitat according to the SWH criteria, but because the areas are far from the notches, it is unlikely they were affected by notching.

Monitoring Time Scales

Geomorphic adjustments in rehabilitation projects require some amount of time before a presumptive dynamic equilibrium can be achieved, but empirical data and theory are lacking to estimate how long this time period is, and therefore how long monitoring should continue. As sediment transport is necessary for geomorphic adjustment, and sediment transport is typically a power function of discharge, high discharge events will probably be necessary to build SWH areas and move hypsometric curves upward. Habitat assessments before equilibration takes place will substantially underestimate the contribution of the project to ultimate available acreage. The surveys reported here took place within approximately one month of notching so opportunity for adjustment to high flows was very limited.

Whereas some period of time is necessary for measurable adjustment to take place, long periods between surveys my obscure changes resulting from engineered modifications and those attributable to background sediment-transport dynamics. Therefore, it is preferable to have a minimal time between the pre-modification survey and an initial post-modification survey. Additional post-modification surveys would be planned at increasing time intervals, and to capture effects of specific flood events, until adjustment to an equilibrium morphology is determined. This approach would minimize confounding effects of modification with background geomorphic variation.

Some sites may have unusually high rates of background geomorphic variation that would make them unsuitable for assessments. For example, the March 2002 survey at RM 250.1 was extremely different from the May 2004 survey. Some part of the measured aggradation and degradation may be due to mixing of del-CRP and RTK-GPS elevation calculations, perhaps as much as 2 ft (0.7 m). This error, however, cannot explain the mapped range of elevation change from +13 to -13 ft (+4 to -4 m). In fact, the 2002 and 2004 maps document shifting of the thalweg of the main channel by as much as 390 ft (120 m) in this time interval. Because this site is at the junction of the Grand River with the Missouri, background geomorphic changes may be especially dynamic. Areas like this may not be well suited for isolating the effects of rehabilitation activities from background variation.

Evaluating Depth and Velocity

The definition of SWH is based on a range of depth and current velocity. Both of these quantities are highly sensitive to discharge, so evaluation of available habitat depends strongly on consistently conducting measurements at the index discharge, or within an accepted range. Depth distribution can be calculated relative to the bottom elevation using procedures discussed above, but current velocity must be measured at the index discharge unless effort is invested in multidimensional hydraulic modeling. Velocities were mapped in this study at discharges that poorly represent the median July 15 – August 15 flow because waiting for steady, targeted discharges was not an option. Velocity evaluations can be improved if sufficient time is available to measure target discharges.

An inherent tradeoff in the evaluation procedure is that high water improves ability to evaluate all possible elevation contributions to SWH, but target discharges are preferred to evaluate velocities. Surveys at stages where the survey boat can navigate over the wing dikes would also be able to measure notch geometries directly. This suggests that two types of assessment surveys could be considered: habitat surveys at specific target discharge ranges, and geomorphic surveys at higher water. The habitat surveys would assess whether the rehabilitation is performing in ways thought to support important species (that is, increasing the areal extent of habitat that conforms to the SWH definition) and the geomorphic surveys would track geomorphic adjustment of the project as sediment transport alters topography.

Summary and Conclusions

Five wing dikes were surveyed in May 2004 after notching as part of shallow-water habitat (SWH) rehabilitation activities carried out by the U.S. Army Corps of Engineers. Surveys included high-

resolution hydroacoustic depth, velocity, and substrate mapping. Relations of bottom elevations within the wing dike fields to index discharges and water-surface elevations indicate that little SWH existed before or immediately after notching. This result is not unexpected, as significant geomorphic adjustment may require large flow events. Depth, velocity, and substrate measurements in the post-rehabilitation time period provide baseline data for monitoring ongoing changes. Differences in elevation and substrate between pre- and post-modification surveys were noted at all sites, supporting the idea that modifications have altered sediment transport and therefore may provide additional habitat meeting SWH criteria as time passes. Most dike fields documented substantial aggradation and replacement of mud substrate with sandier sediment. It is not known precisely how much of the elevation and substrate changes can be attributed directly to notching and how much would result from normal discharge variation. Comparisons of the May 2004 elevations with the pre-rehabilitation elevations demonstrate that significant change can occur (as much as ±13 ft), but because of variable timing of pre-rehabilitation surveys, it is difficult to attribute change directly to notching. Whereas geomorphic changes associated with dike modifications can be surveyed over a range of discharges, and depths at target discharges can be estimated, evaluation of velocities requires surveys at or near the specific target discharges.

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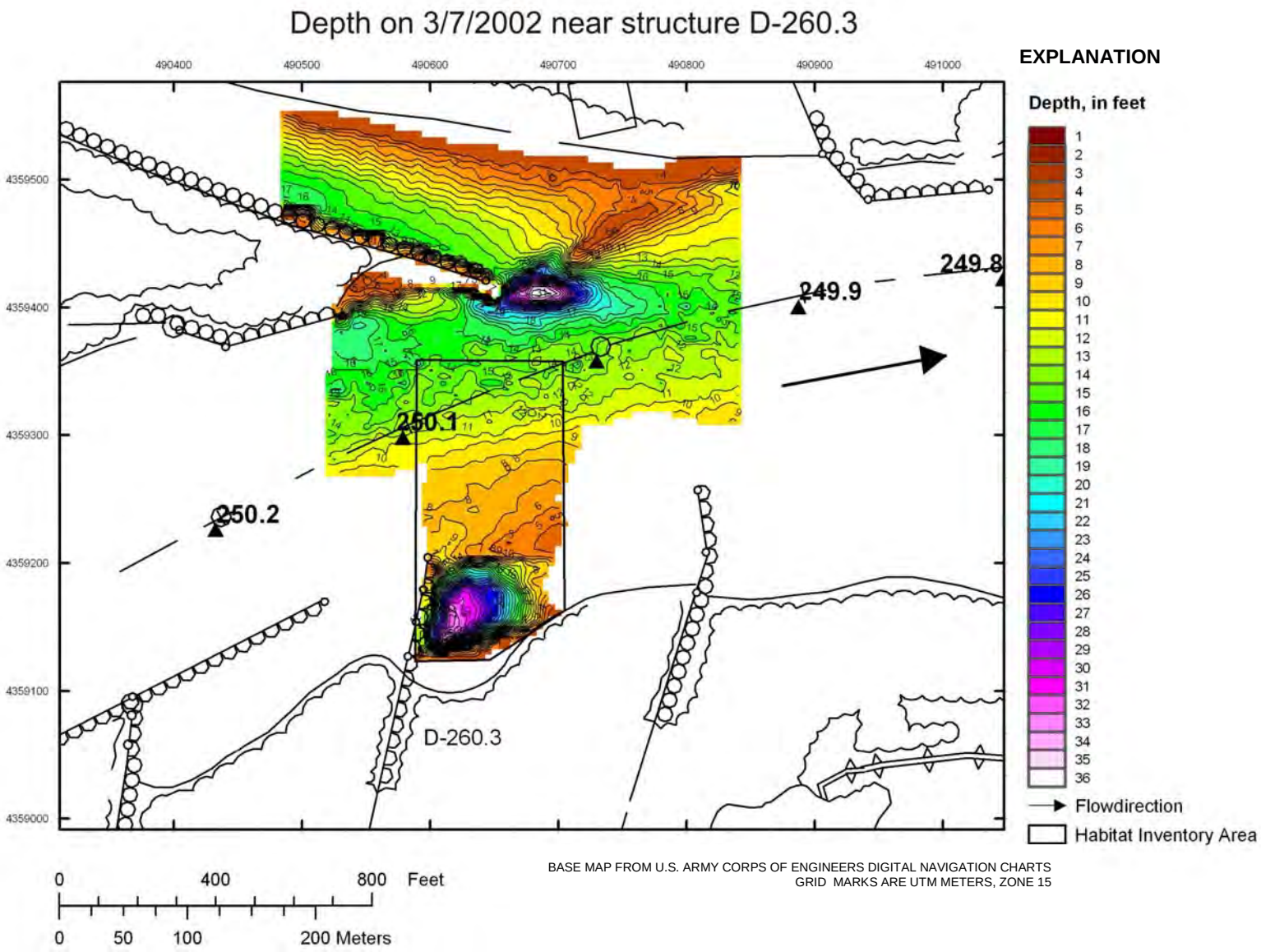
Assessment of Shallow-Water Habitat Availability in Modified Dike Structures, Lower Missouri River, 2004

By Robert B. Jacobson, Caroline M. Elliott, and Harold E. Johnson

Appendix

Open-File Report 2004-1409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4359100
4359000
249.8
249.9
250.1
250.2
D-260.3
EXPLANATION
Depth, in feet
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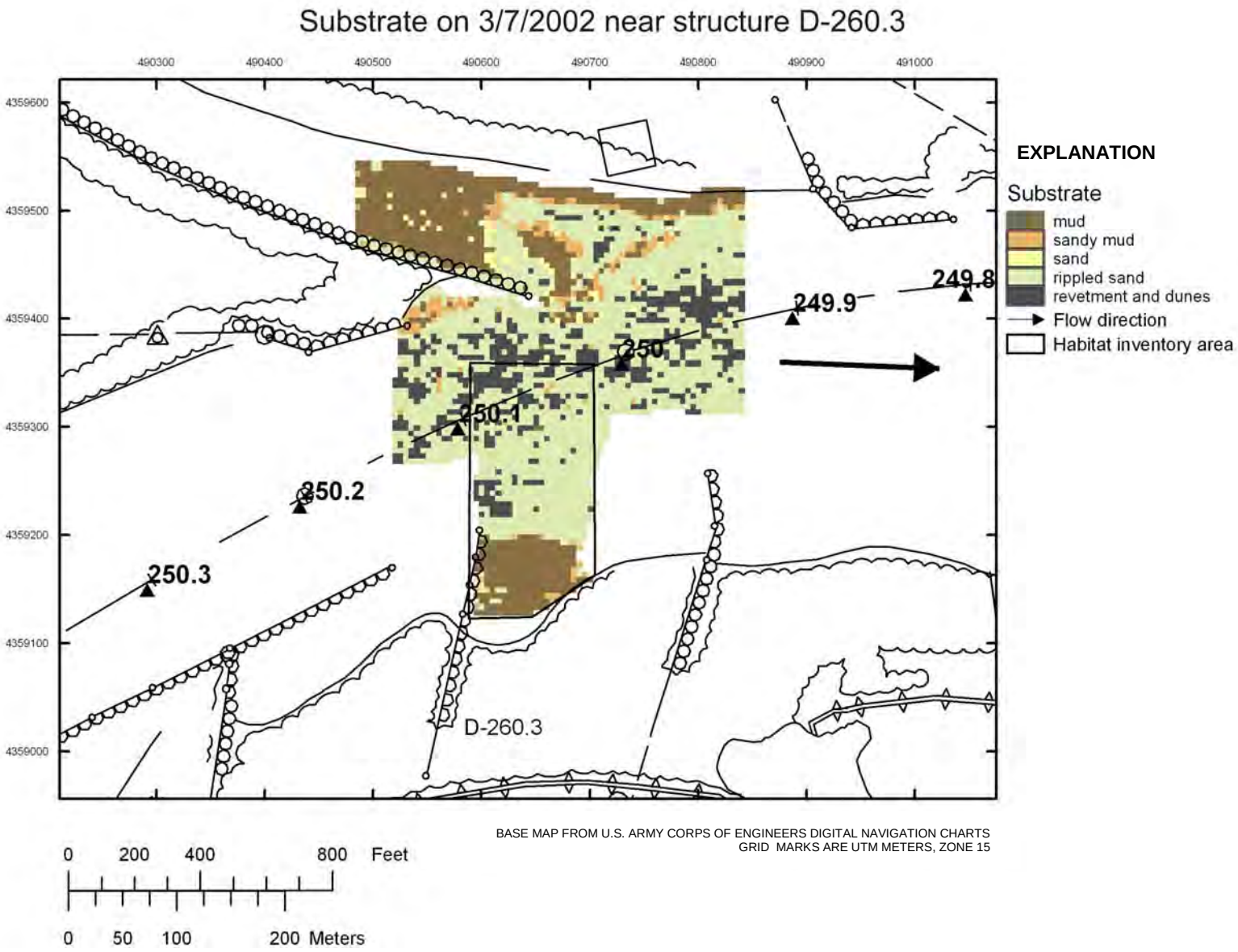
34
35
36
Flowdirection
Habitat Inventory Area
0
400
800 Feet
0
50
100
200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.1


Substrate on 3/7/2002 near structure D-260.3
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250.2
250.3
D-260.3
EXPLANATION
Substrate
mud
sandy mud
sand
rippled sand
revetment and dunes
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.2

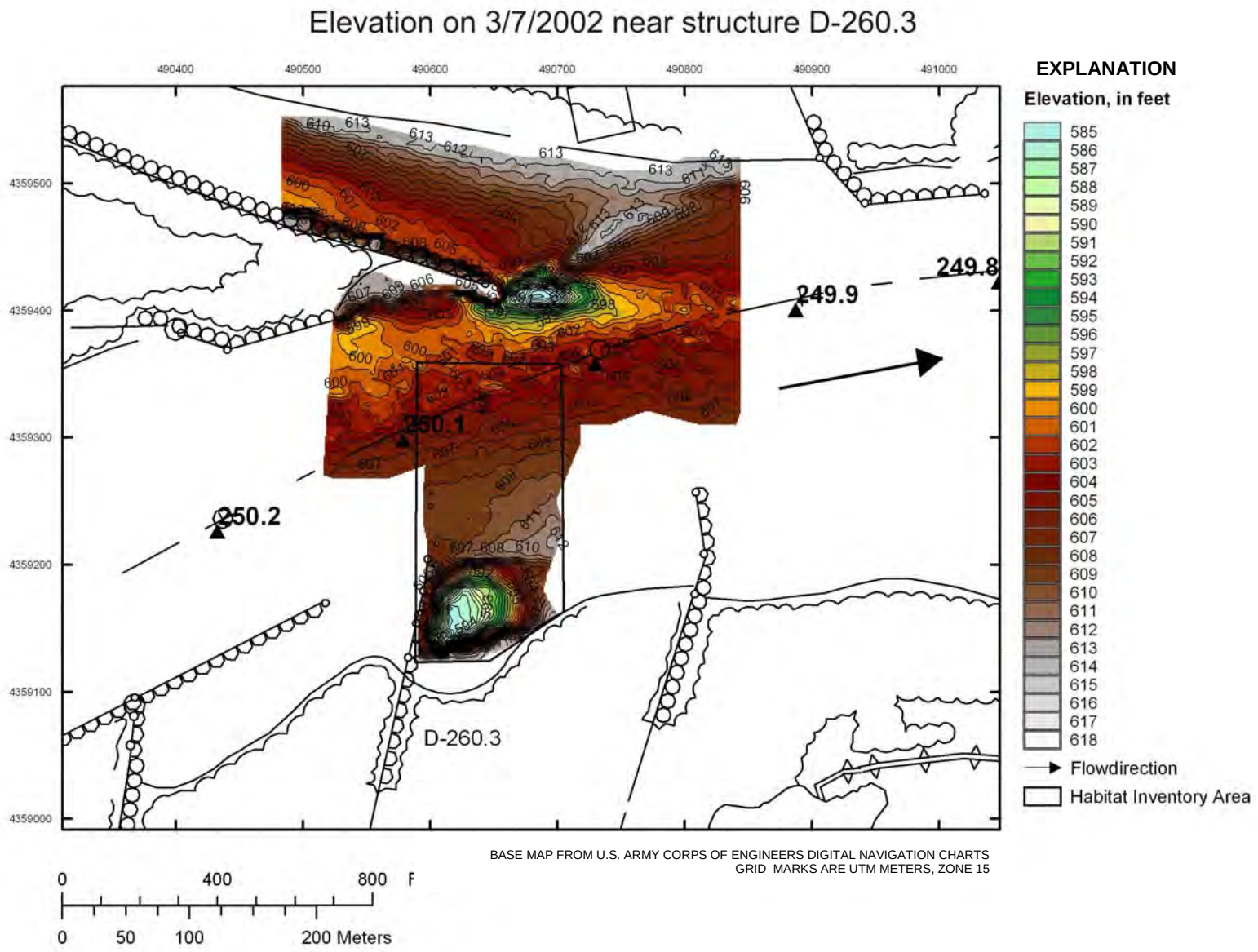
Elevation on 3/7/2002 near structure D-260.3
490400
490500
490600
490700
490800
490900
491000
4359500
4359400
4359300
4359200
4359100
4359000
249.8
249.9
250.1
250.2
D-260.3
EXPLANATION
Elevation, in feet
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
Flowdirection
Habitat Inventory Area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
400
800
0
50
100
200 Meters

Figure A.3

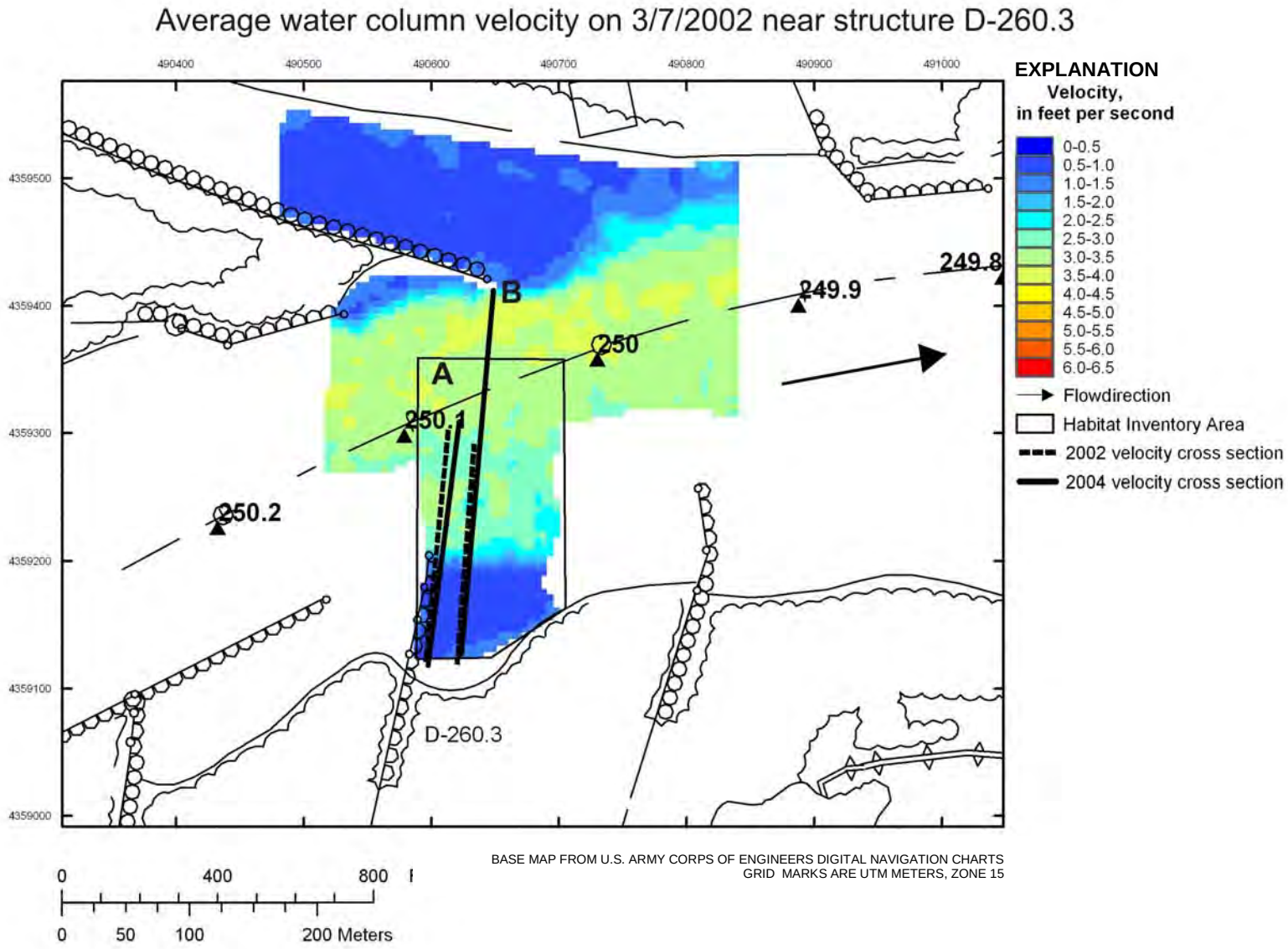
Average water column velocity on 3/7/2002 near structure D-260.3
490400
490500
490600
490700
490800
490900
491000
4359500
4359400
4359300
4359200
4359100
4359000
B
A
249.8
249.9
250
250.1
250.2
D-260.3
EXPLANATION
Velocity,
in feet per second
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
Flowdirection
Habitat Inventory Area
2002 velocity cross section
2004 velocity cross section
0
400
800
0
50
100
200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.4

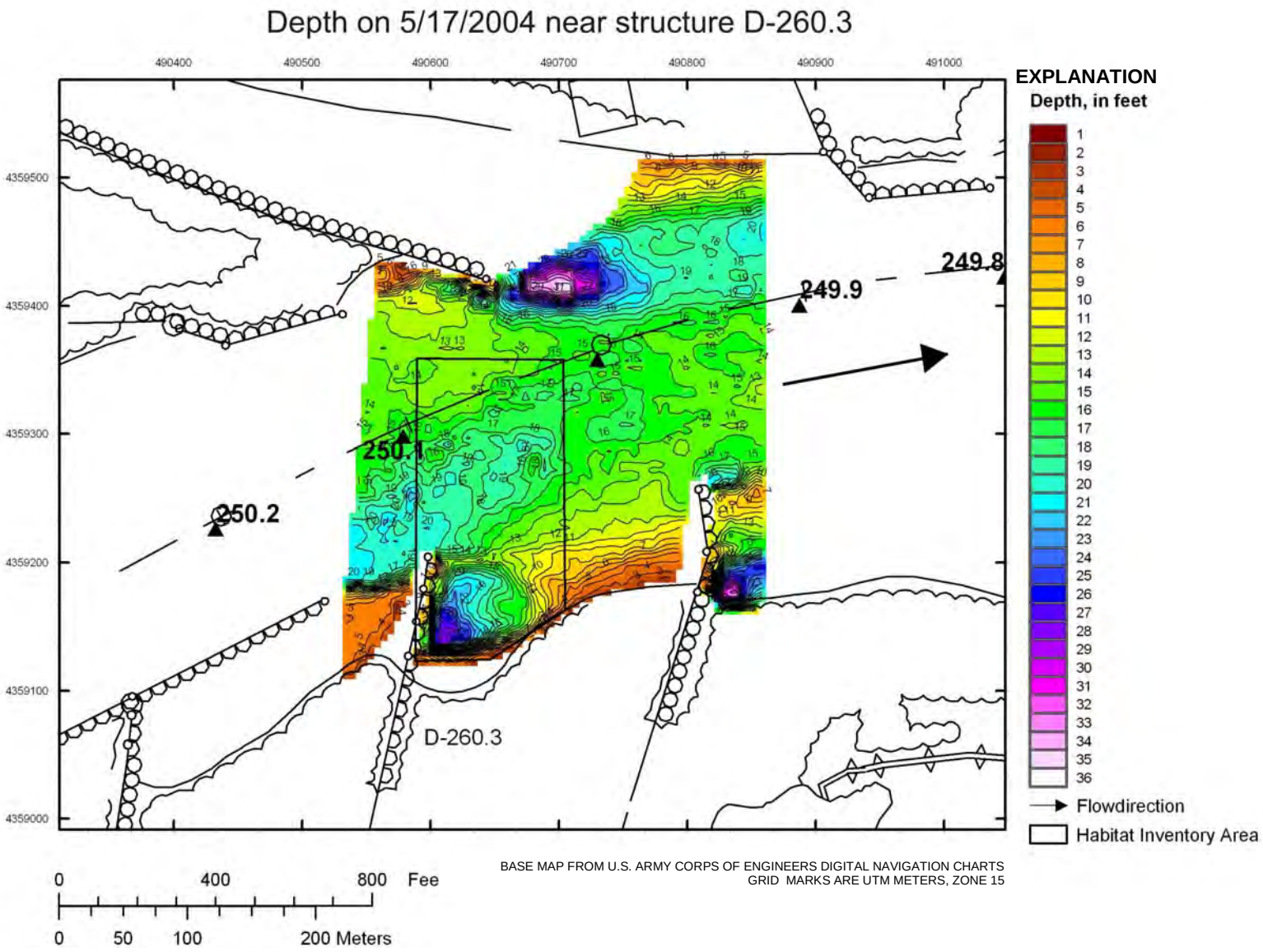
Depth on 5/17/2004 near structure D-260.3
490400
490500
490600
490700
490800
490900
491000
4359500
4359400
4359300
4359200
4359100
4359000
249.8
249.9
250.1
250.2
D-260.3
EXPLANATION
Depth, in feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
Flowdirection
Habitat Inventory Area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
400
800 Fee
0
50
100
200 Meters

Figure A.5

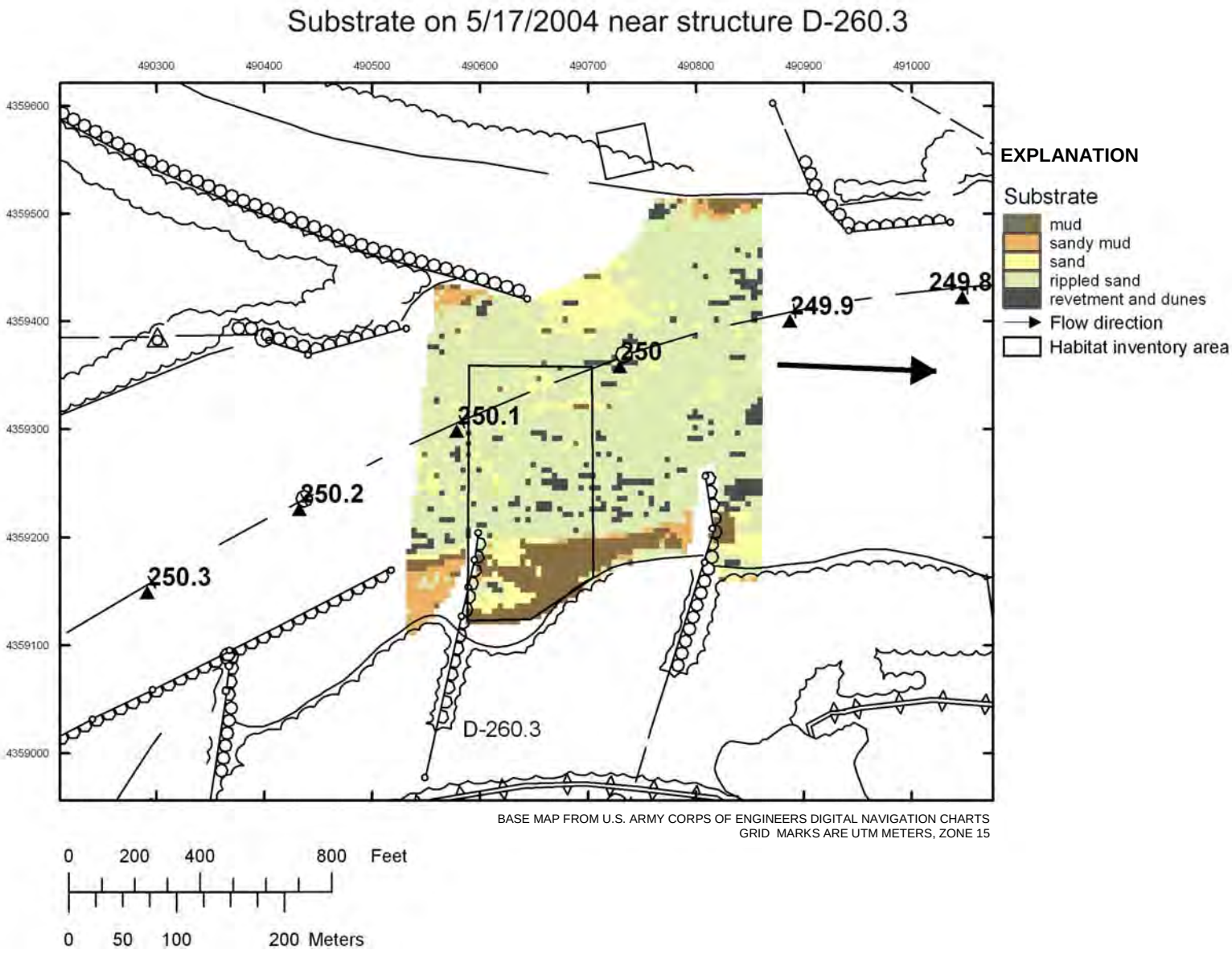
Substrate on 5/17/2004 near structure D-260.3
490300
490400
490500
490600
490700
490800
490900
491000
4359600
4359500
4359400
4359300
4359200
4359100
4359000
249.8
249.9
250
250.1
250.2
250.3
D-260.3
EXPLANATION
Substrate
mud
sandy mud
sand
rippled sand
revetment and dunes
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.6

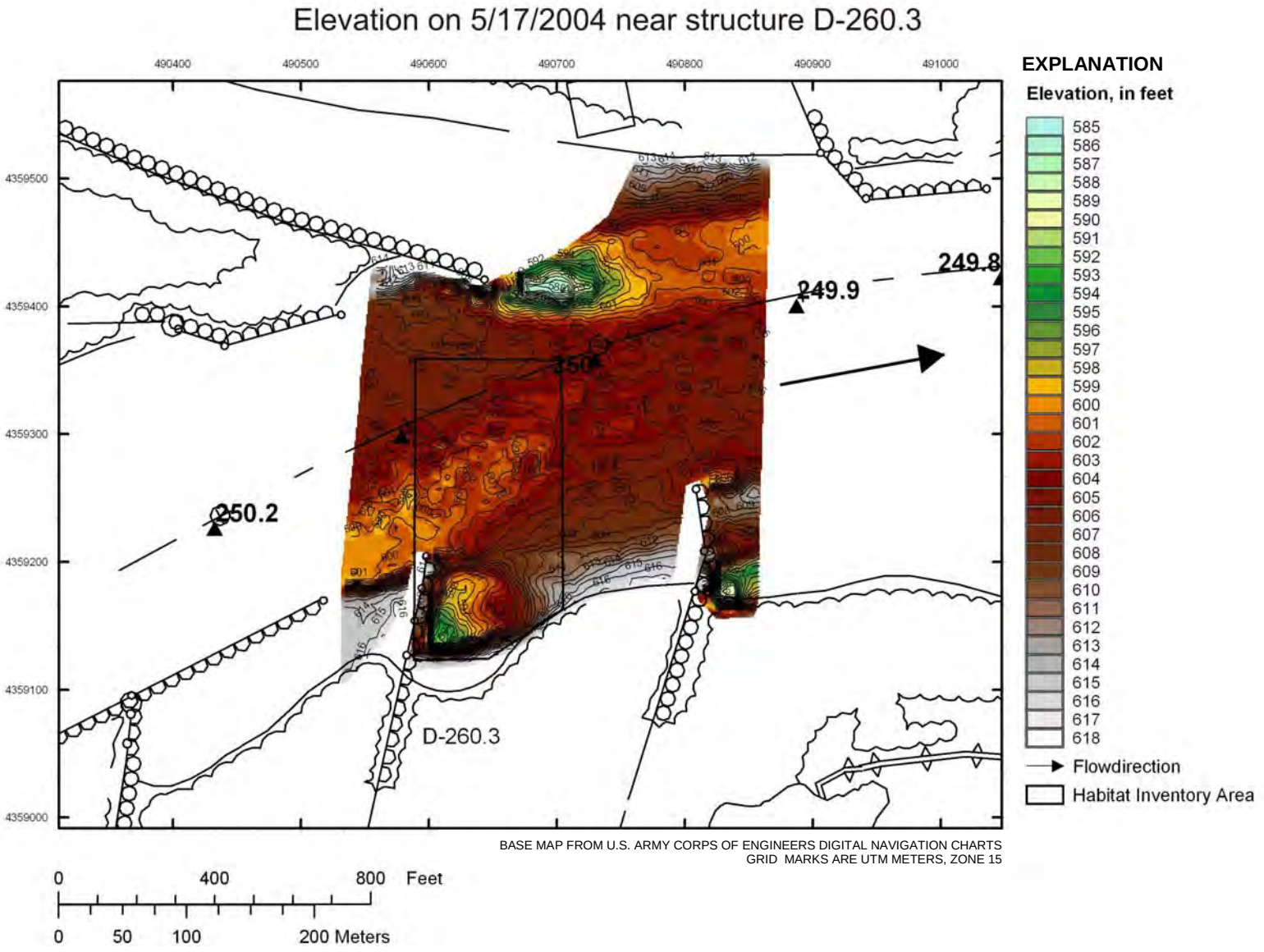
Elevation on 5/17/2004 near structure D-260.3
490400
490500
490600
490700
490800
490900
491000
4359500
4359400
4359300
4359200
4359100
4359000
249.8
249.9
250
250.2
D-260.3
EXPLANATION
Elevation, in feet
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
Flowdirection
Habitat Inventory Area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
400
800 Feet
0
50
100
200 Meters

Figure A.7

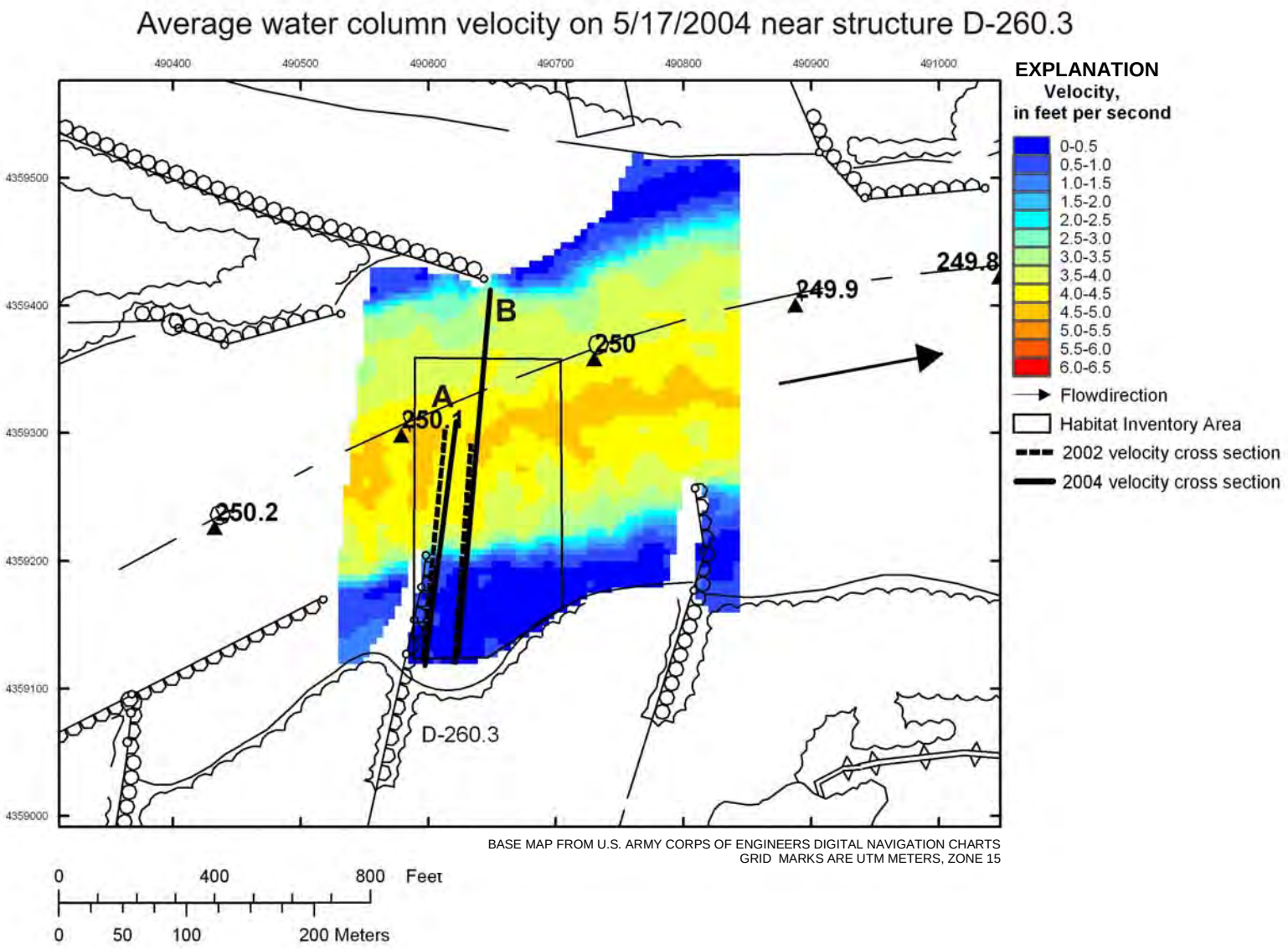
Average water column velocity on 5/17/2004 near structure D-260.3
490400
490500
490600
490700
490800
490900
491000
4359500
4359400
4359300
4359200
4359100
4359000
EXPLANATION
Velocity,
in feet per second
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
Flowdirection
Habitat Inventory Area
2002 velocity cross section
2004 velocity cross section
249.8
249.9
250
250.1
250.2
A
B
D-260.3
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
400
800
Feet
0
50
100
200 Meters

Figure A.8

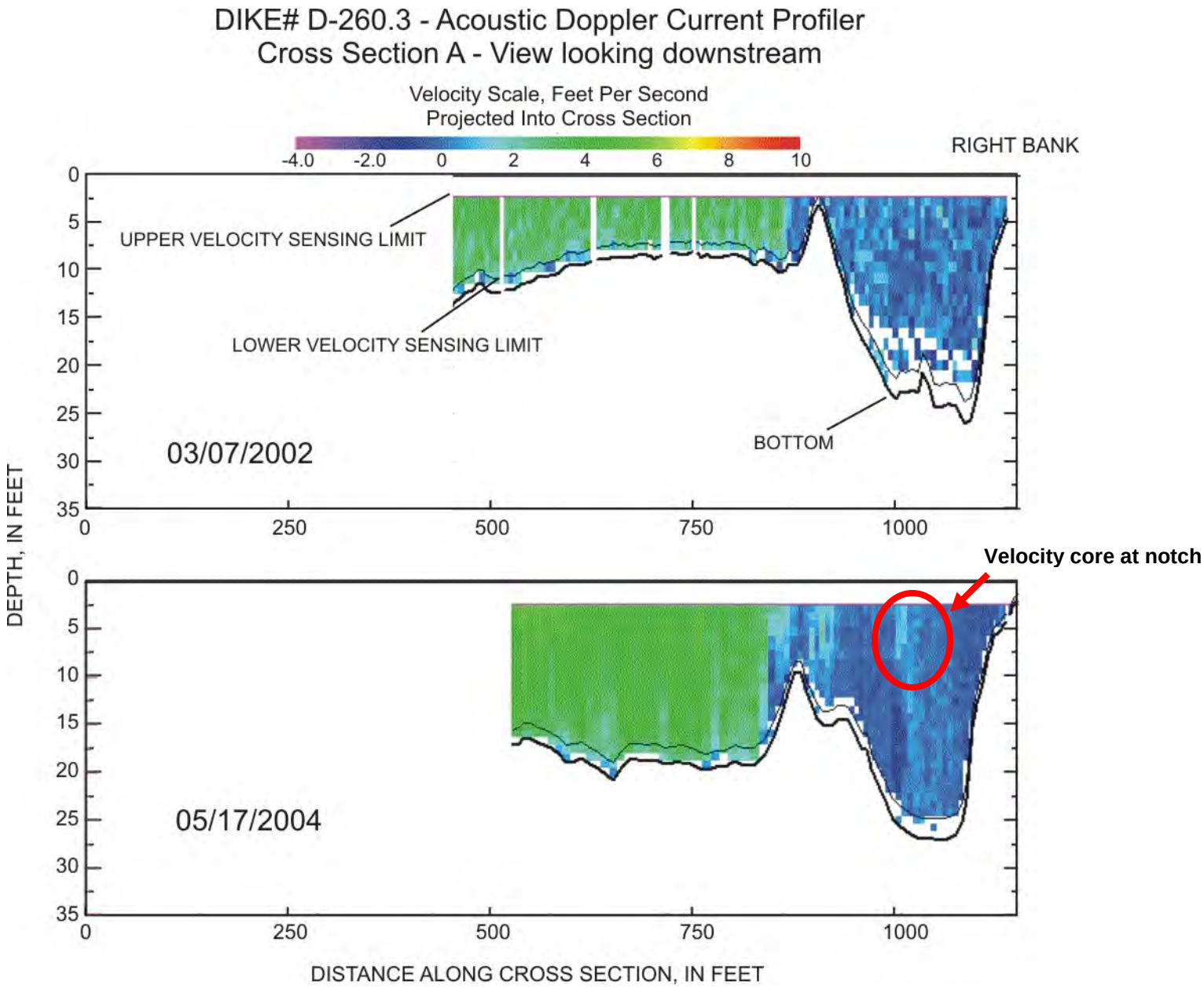
DIKE# D-260.3 - Acoustic Doppler Current Profiler
Cross Section A - View looking downstream
Velocity Scale, Feet Per Second
Projected Into Cross Section
-4.0 -2.0 0 2 4 6 8 10
RIGHT BANK
UPPER VELOCITY SENSING LIMIT
LOWER VELOCITY SENSING LIMIT
BOTTOM
03/07/2002
05/17/2004
Velocity core at notch
DEPTH, IN FEET
0 5 10 15 20 25 30 35
0 250 500 750 1000
DISTANCE ALONG CROSS SECTION, IN FEET

Figure A.9

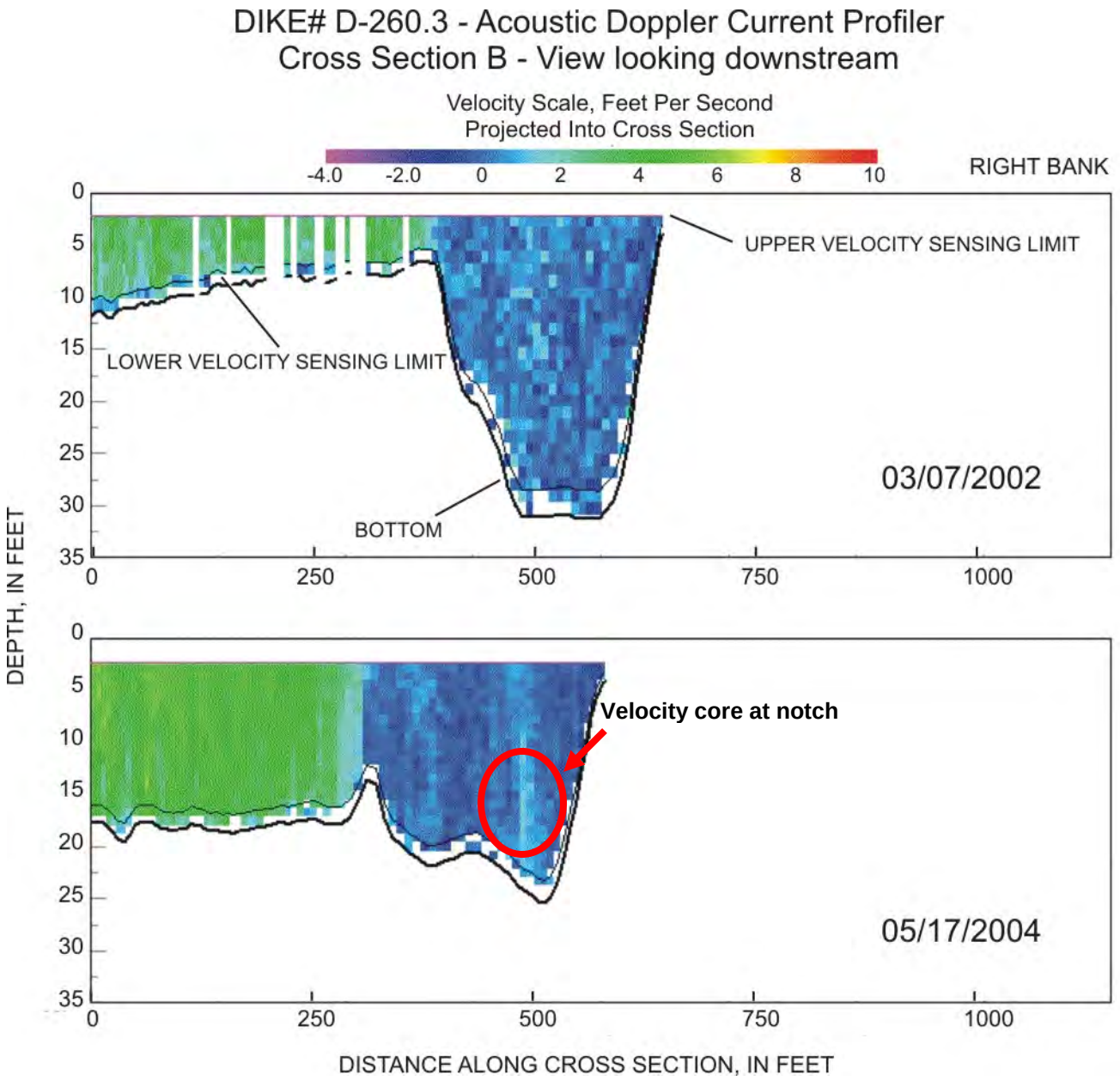
DIKE# D-260.3 - Acoustic Doppler Current Profiler
Cross Section B - View looking downstream
Velocity Scale, Feet Per Second
Projected Into Cross Section
-4.0
-2.0
0
2
4
6
8
10
RIGHT BANK
UPPER VELOCITY SENSING LIMIT
LOWER VELOCITY SENSING LIMIT
BOTTOM
03/07/2002
Velocity core at notch
05/17/2004
DEPTH, IN FEET
0
5
10
15
20
25
30
35
0
250
500
750
1000
DISTANCE ALONG CROSS SECTION, IN FEET

Figure A.10

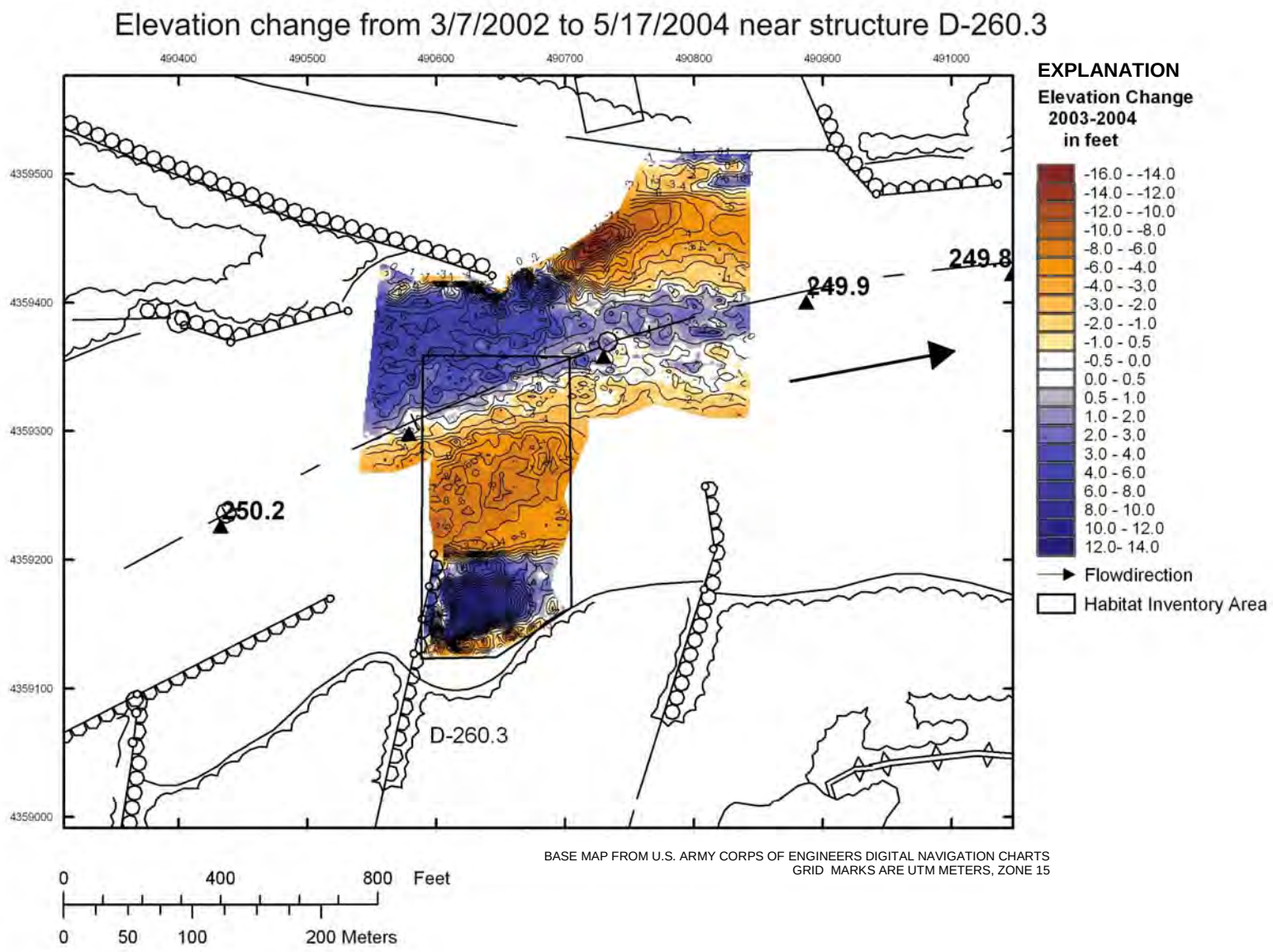
Elevation change from 3/7/2002 to 5/17/2004 near structure D-260.3
490400
490500
490600
490700
490800
490900
491000
4359500
4359400
4359300
4359200
4359100
4359000
249.8
249.9
250.2
D-260.3
EXPLANATION
Elevation Change
2003-2004
in feet
-16.0 - -14.0
-14.0 - -12.0
-12.0 - -10.0
-10.0 - -8.0
-8.0 - -6.0
-6.0 - -4.0
-4.0 - -3.0
-3.0 - -2.0
-2.0 - -1.0
-1.0 - 0.5
-0.5 - 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 6.0
6.0 - 8.0
8.0 - 10.0
10.0 - 12.0
12.0- 14.0
Flowdirection
Habitat Inventory Area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
400
800 Feet
0
50
100
200 Meters

Figure A.11

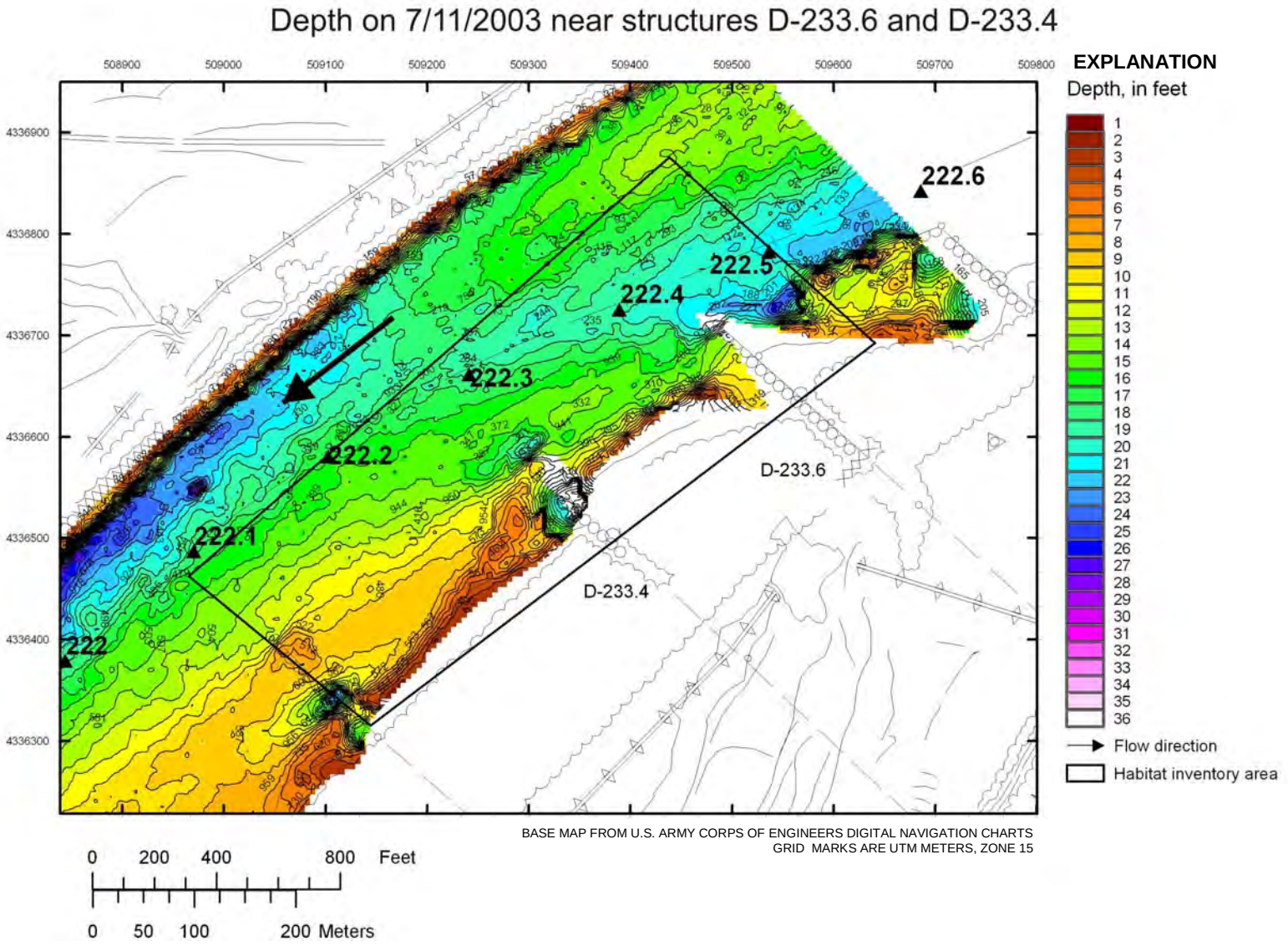
Depth on 7/11/2003 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
509800
4336900
4336800
4336700
4336600
4336500
4336400
4336300
222.6
222.5
222.4
222.3
222.2
222.1
222
D-233.6
D-233.4
EXPLANATION
Depth, in feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.12

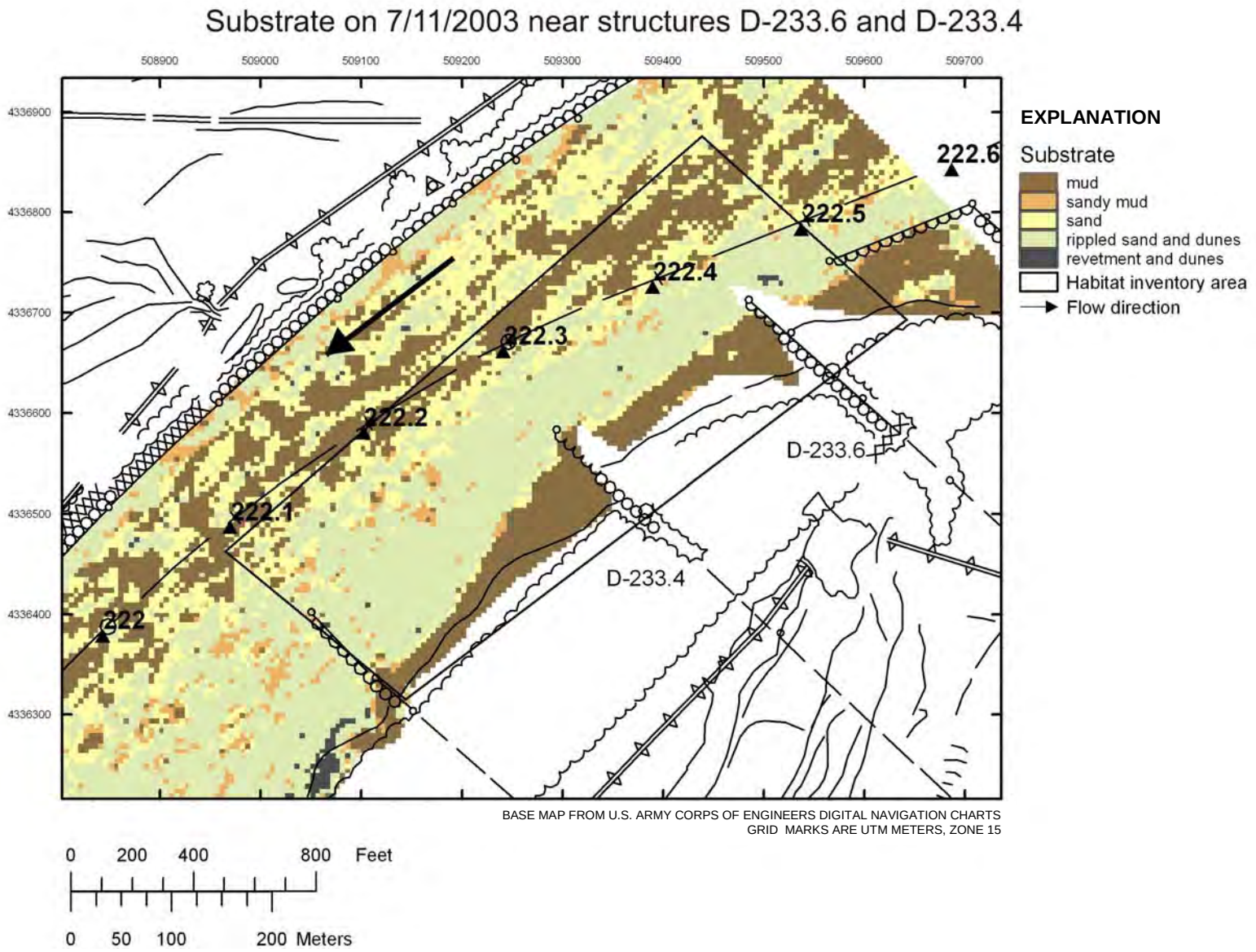
Substrate on 7/11/2003 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
4336900
4336800
4336700
4336600
4336500
4336400
4336300
222.6
222.5
222.4
222.3
222.2
222.1
222
D-233.6
D-233.4
EXPLANATION
Substrate
mud
sandy mud
sand
rippled sand and dunes
revetment and dunes
Habitat inventory area
Flow direction
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.13

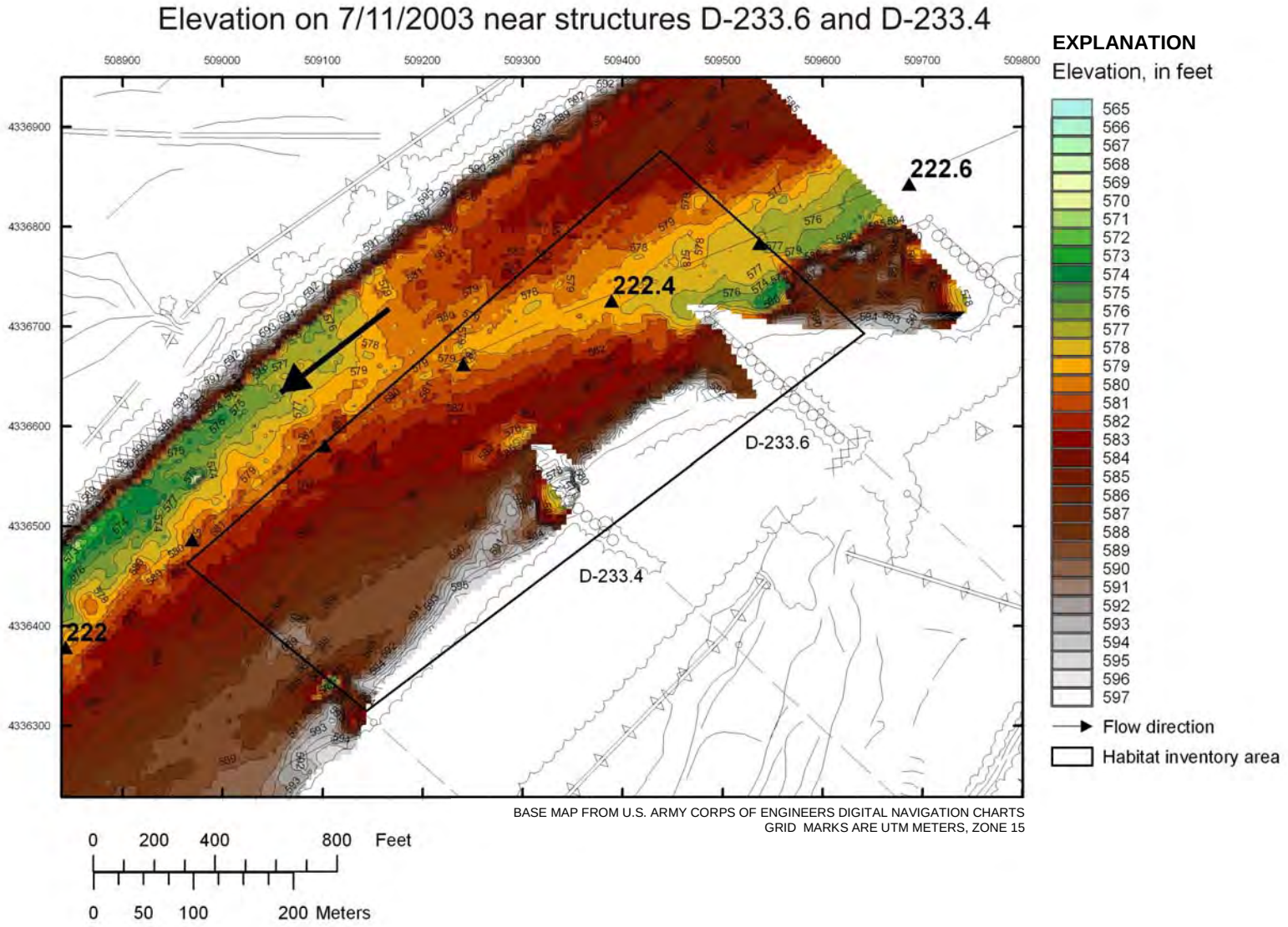
Elevation on 7/11/2003 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
509800
4336900
4336800
4336700
4336600
4336500
4336400
4336300
222.6
222.4
222
D-233.6
D-233.4
EXPLANATION
Elevation, in feet
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.14

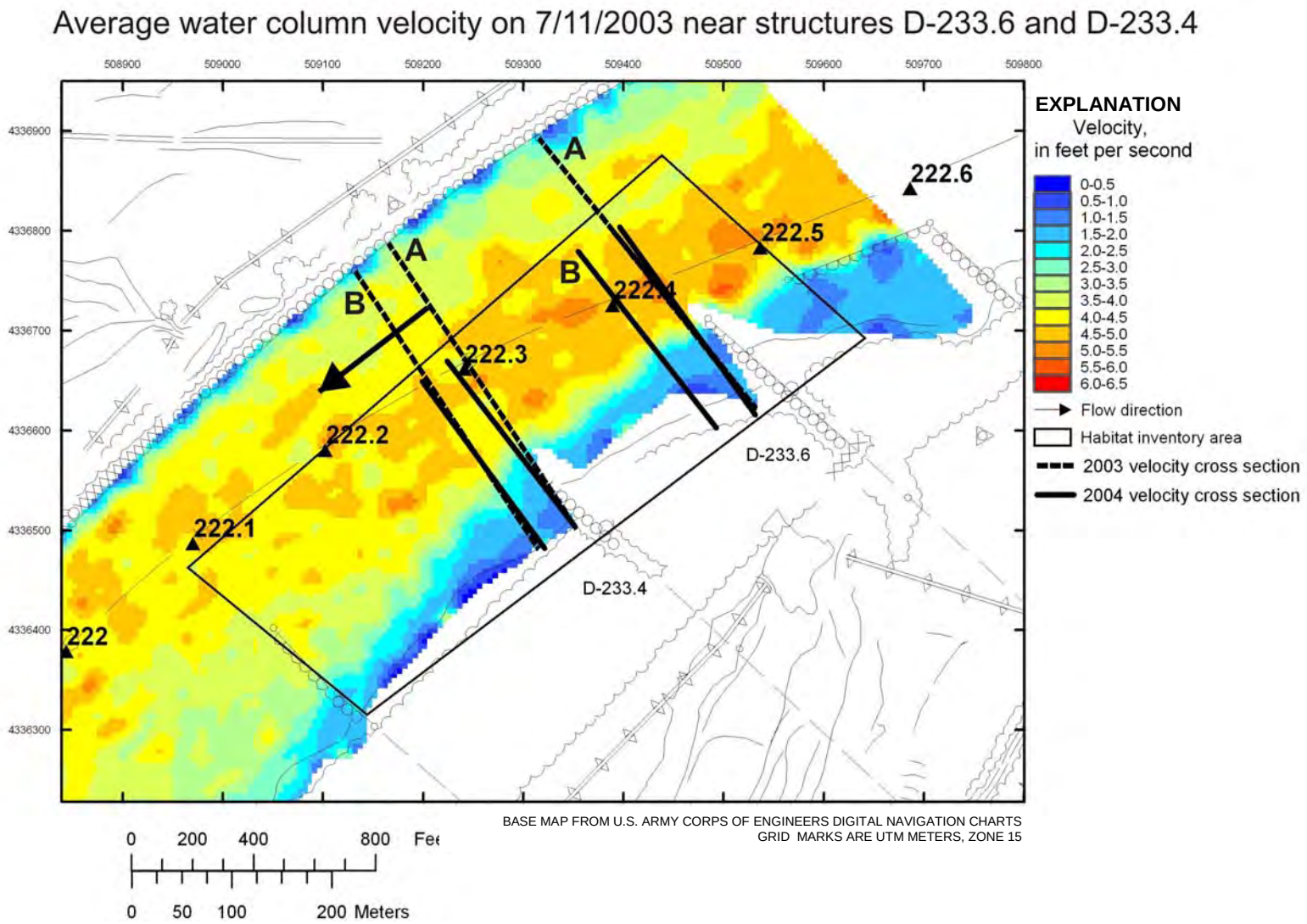
Average water column velocity on 7/11/2003 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
509800
4336900
4336800
4336700
4336600
4336500
4336400
4336300
A
A
B
B
222.6
222.5
222.4
222.3
222.2
222.1
222
D-233.6
D-233.4
EXPLANATION
Velocity,
in feet per second
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
Flow direction
Habitat inventory area
2003 velocity cross section
2004 velocity cross section
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Fe
0 50 100 200 Meters

Figure A.15

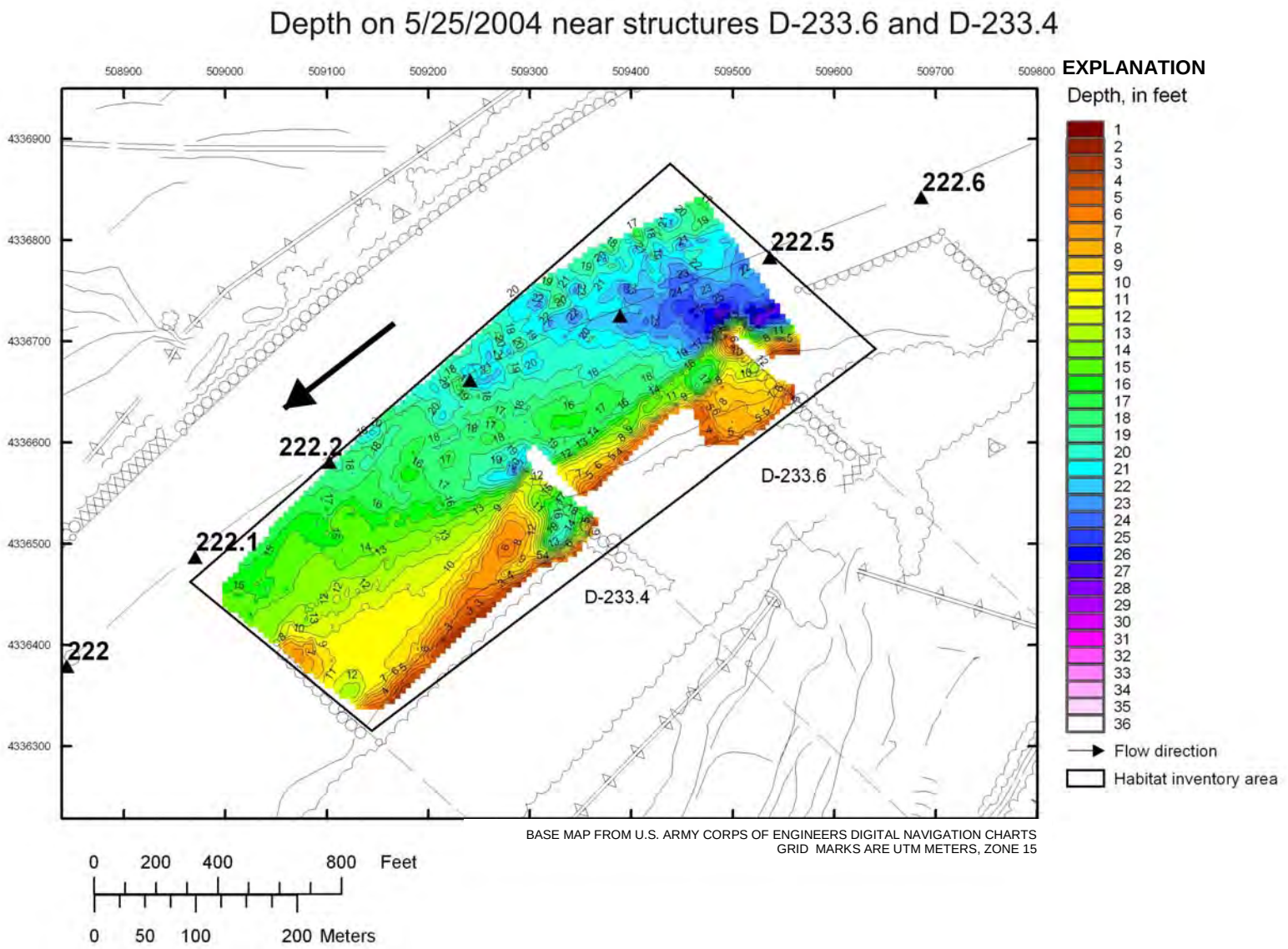
Depth on 5/25/2004 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
509800
4336900
4336800
4336700
4336600
4336500
4336400
4336300
222.6
222.5
222.2
222.1
222
D-233.6
D-233.4
EXPLANATION
Depth, in feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.16

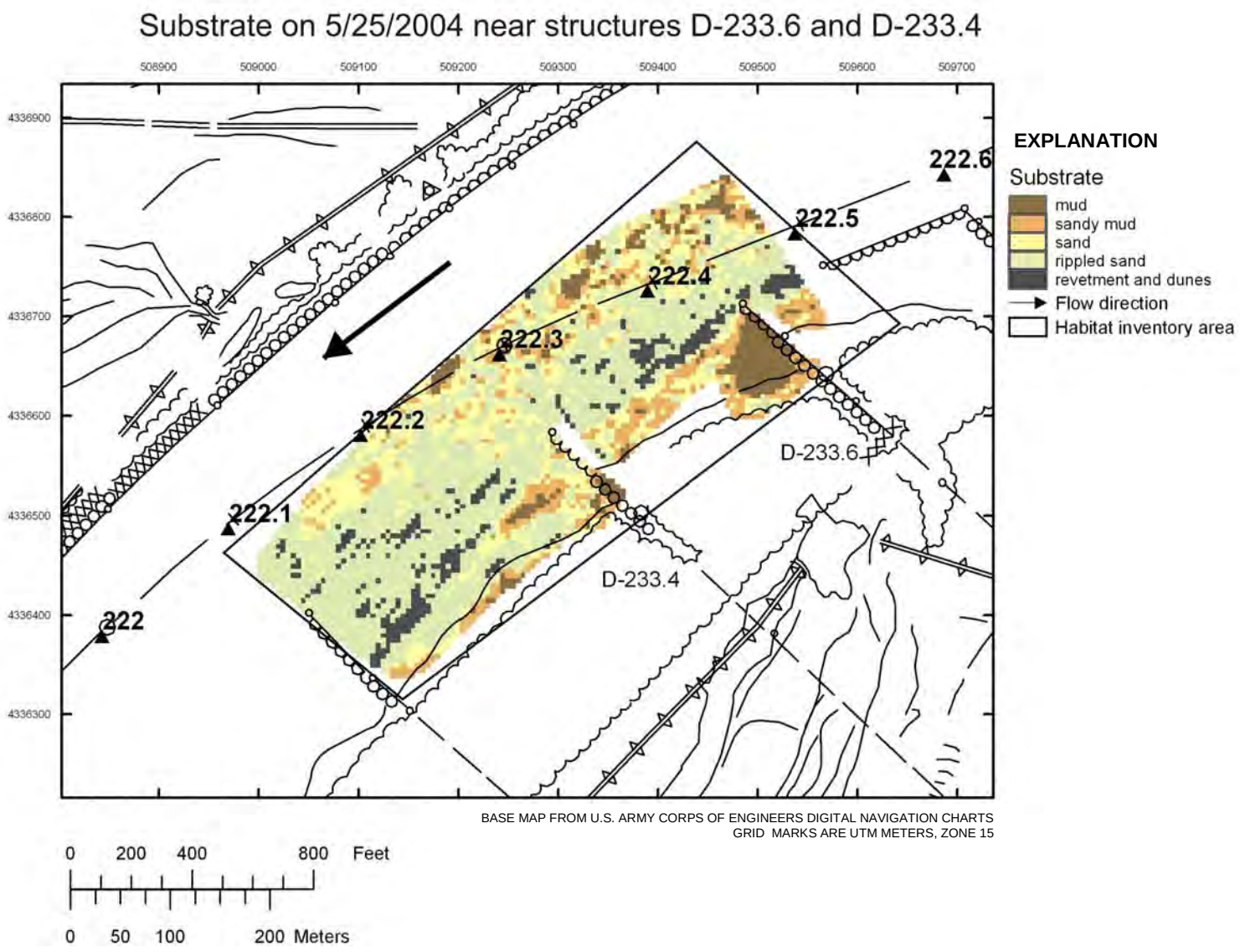
Substrate on 5/25/2004 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
4336900
4336800
4336700
4336600
4336500
4336400
4336300
222.6
222.5
222.4
222.3
222.2
222.1
222
D-233.6
D-233.4
EXPLANATION
Substrate
mud
sandy mud
sand
rippled sand
revetment and dunes
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.17

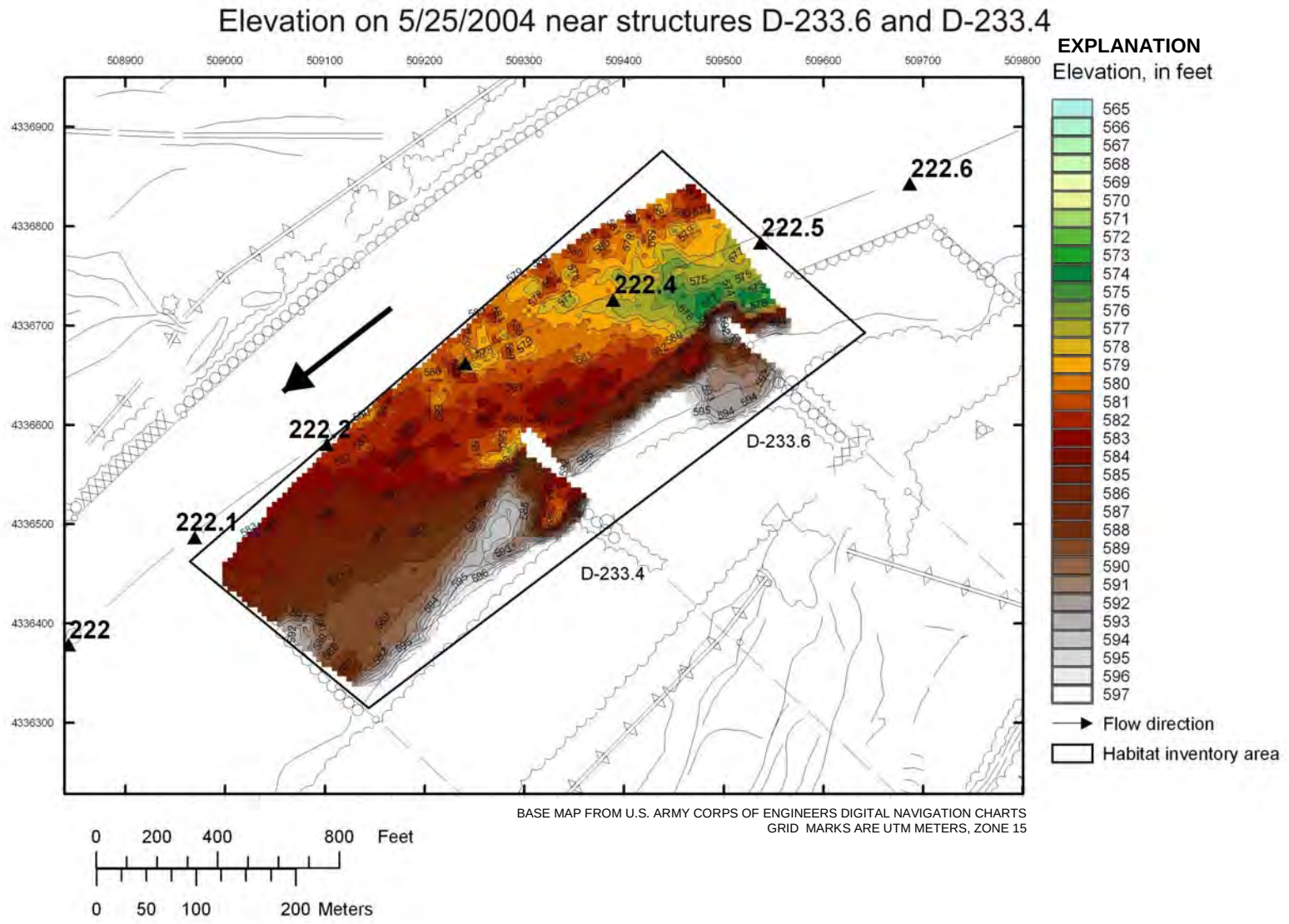
Elevation on 5/25/2004 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
509800
4336900
4336800
4336700
4336600
4336500
4336400
4336300
222.6
222.5
222.4
222.2
222.1
222
D-233.6
D-233.4
EXPLANATION
Elevation, in feet
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.18

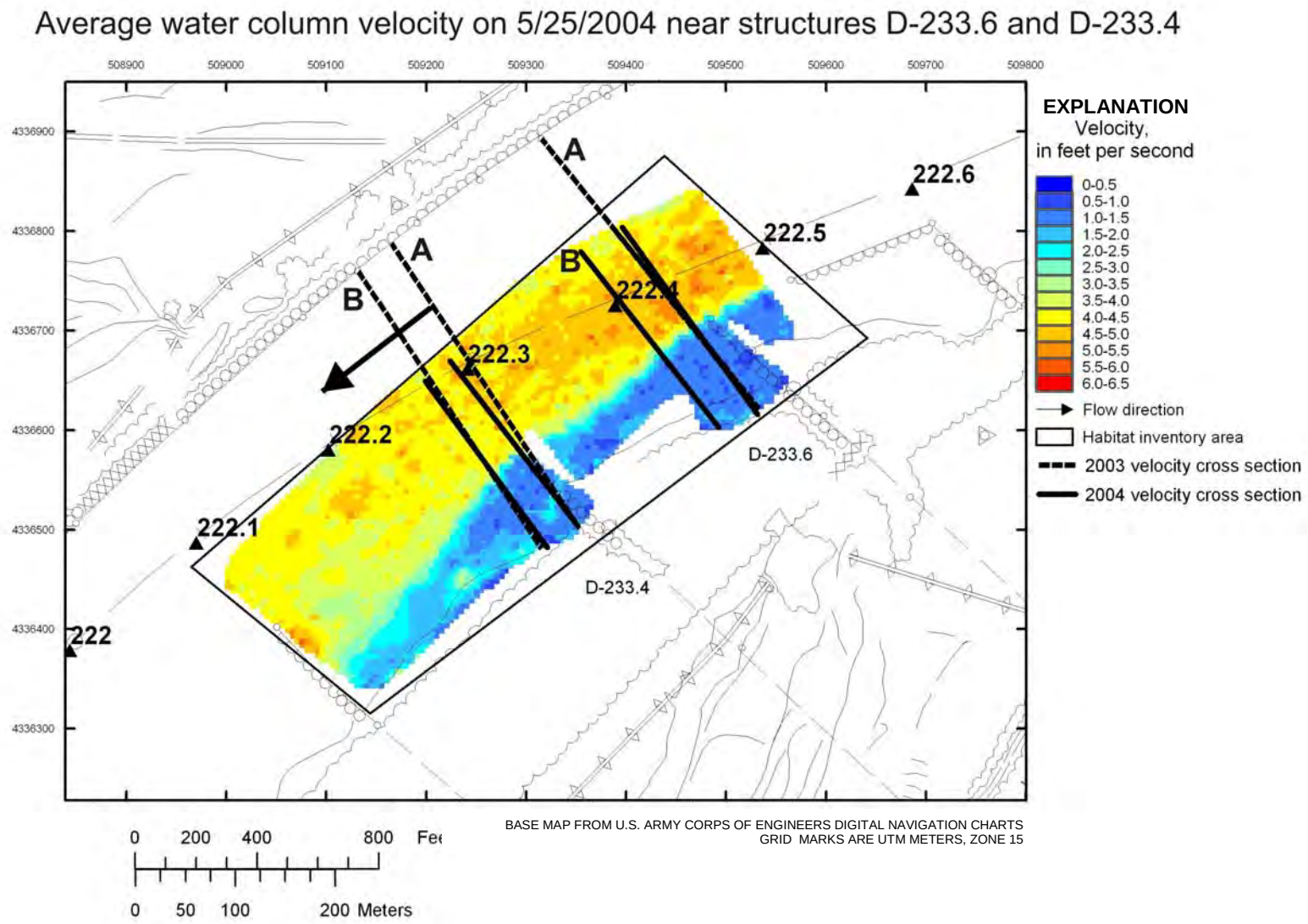
Average water column velocity on 5/25/2004 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
509800
4336900
4336800
4336700
4336600
4336500
4336400
4336300
A
A
B
B
222.6
222.5
222.4
222.3
222.2
222.1
222
D-233.6
D-233.4
EXPLANATION
Velocity,
in feet per second
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
Flow direction
Habitat inventory area
2003 velocity cross section
2004 velocity cross section
0 200 400 800 Fe
0 50 100 200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.19

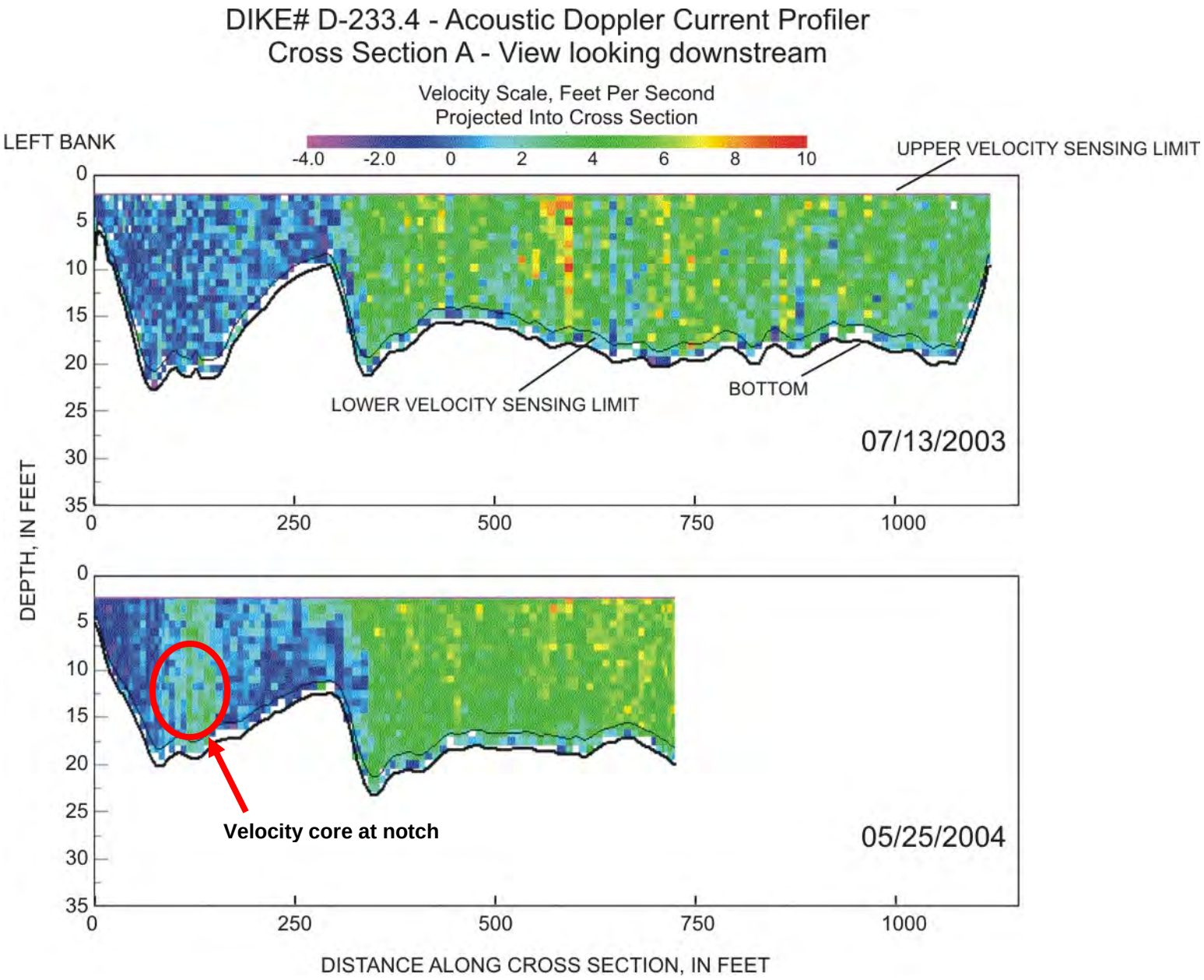
DIKE# D-233.4 - Acoustic Doppler Current Profiler
Cross Section A - View looking downstream
Velocity Scale, Feet Per Second
Projected Into Cross Section
-4.0 -2.0 0 2 4 6 8 10
LEFT BANK
UPPER VELOCITY SENSING LIMIT
LOWER VELOCITY SENSING LIMIT
BOTTOM
07/13/2003
05/25/2004
Velocity core at notch
DEPTH, IN FEET
DISTANCE ALONG CROSS SECTION, IN FEET
0
5
10
15
20
25
30
35
0
250
500
750
1000

Figure A.20

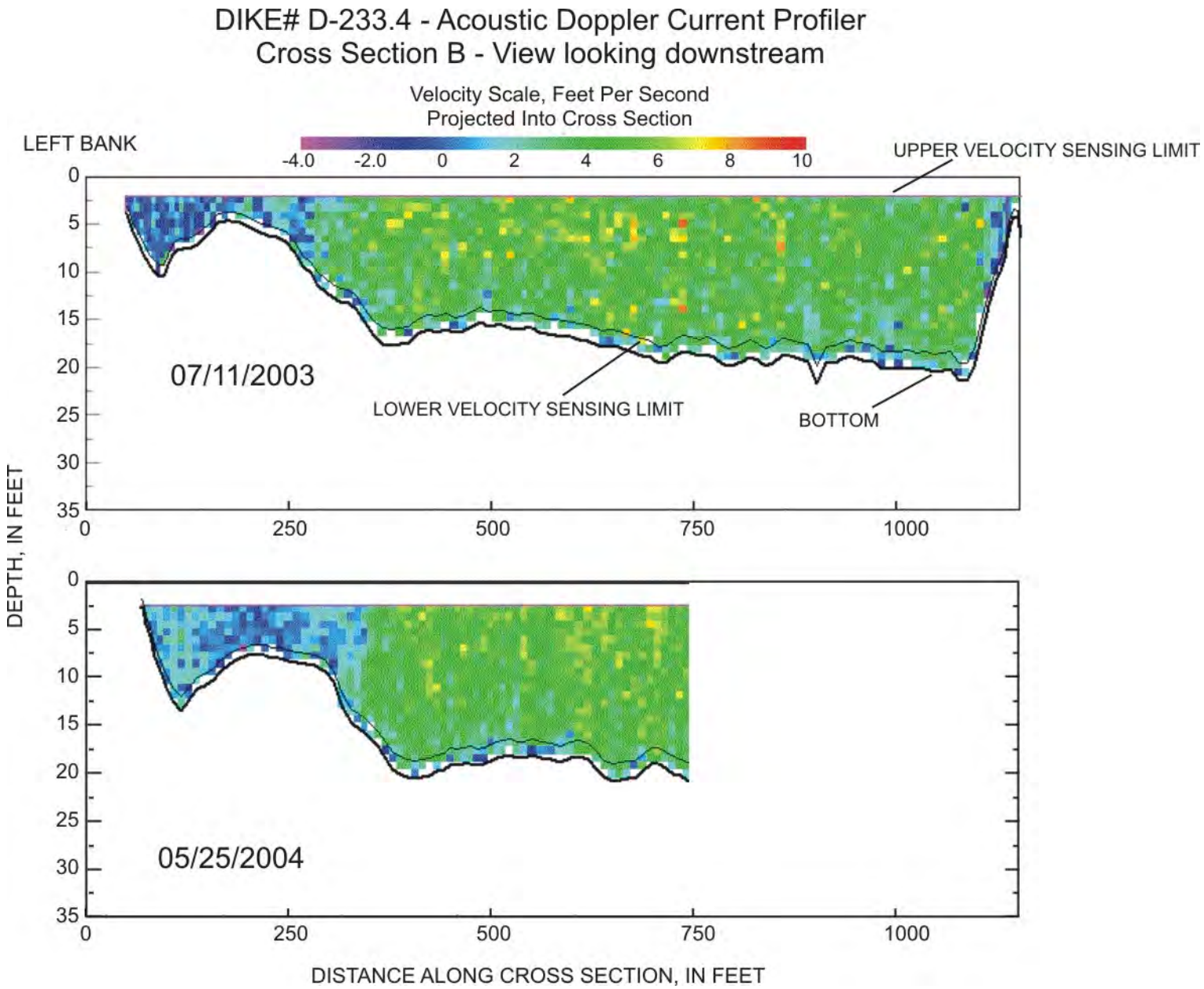
DIKE# D-233.4 - Acoustic Doppler Current Profiler
Cross Section B - View looking downstream
Velocity Scale, Feet Per Second
Projected Into Cross Section
-4.0
-2.0
0
2
4
6
8
10
LEFT BANK
UPPER VELOCITY SENSING LIMIT
LOWER VELOCITY SENSING LIMIT
BOTTOM
07/11/2003
05/25/2004
DEPTH, IN FEET
0
5
10
15
20
25
30
35
0
250
500
750
1000
DISTANCE ALONG CROSS SECTION, IN FEET

Figure A.21

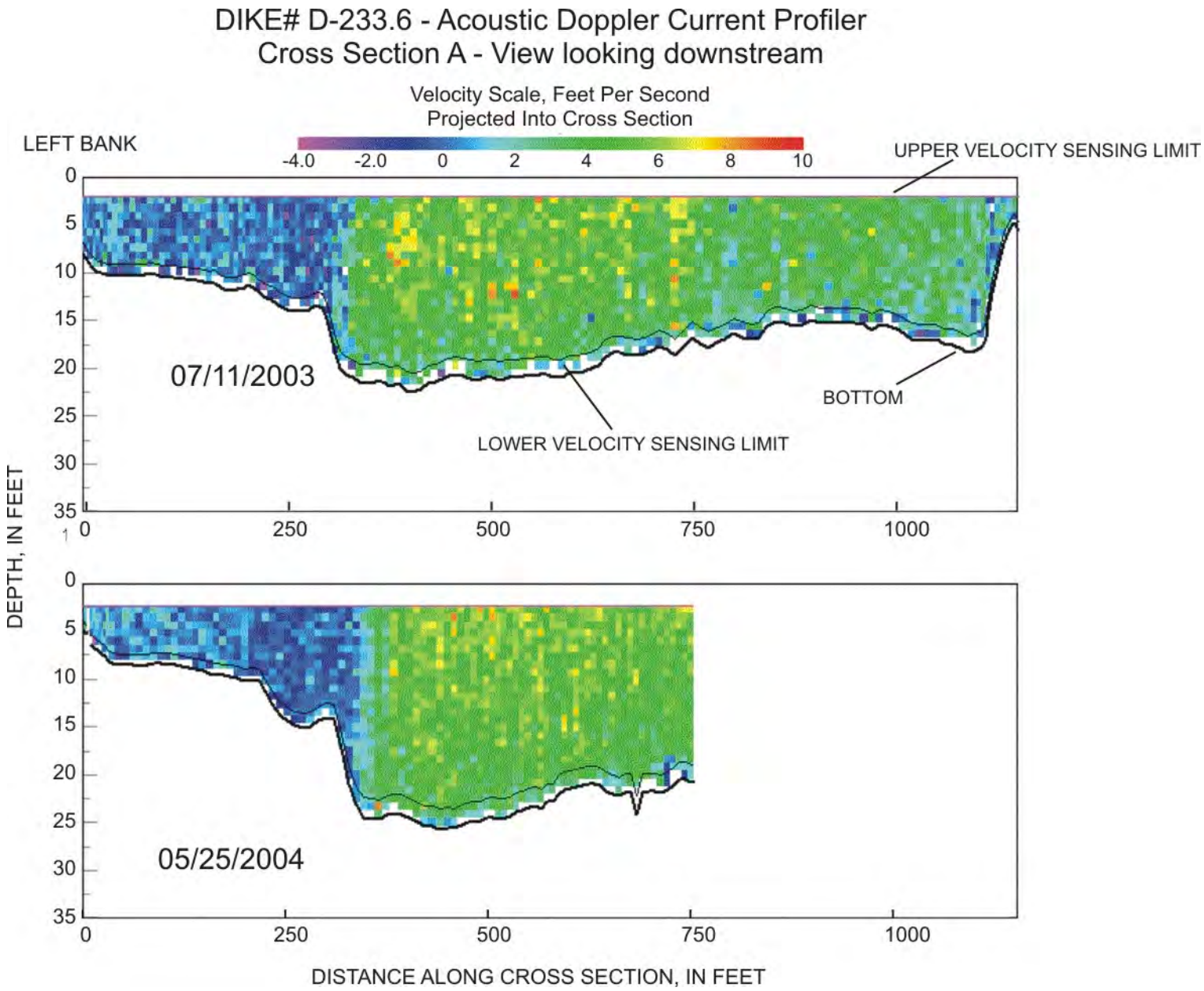
DIKE# D-233.6 - Acoustic Doppler Current Profiler
Cross Section A - View looking downstream
Velocity Scale, Feet Per Second
Projected Into Cross Section
-4.0
-2.0
0
2
4
6
8
10
LEFT BANK
UPPER VELOCITY SENSING LIMIT
BOTTOM
LOWER VELOCITY SENSING LIMIT
07/11/2003
05/25/2004
DEPTH, IN FEET
0
5
10
15
20
25
30
35
0
250
500
750
1000
DISTANCE ALONG CROSS SECTION, IN FEET

Figure A.22

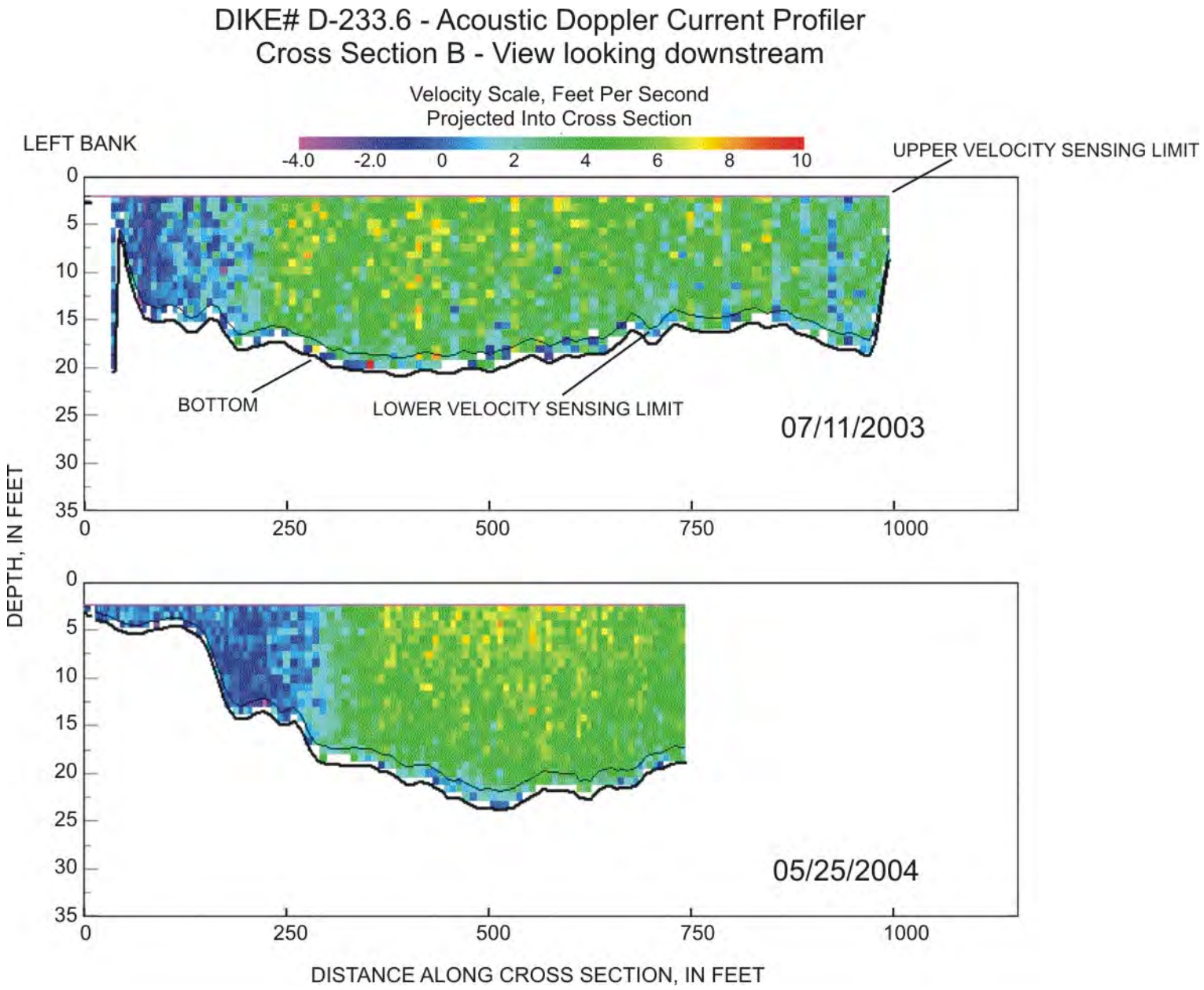
DIKE# D-233.6 - Acoustic Doppler Current Profiler
Cross Section B - View looking downstream
Velocity Scale, Feet Per Second
Projected Into Cross Section
-4.0
-2.0
0
2
4
6
8
10
LEFT BANK
UPPER VELOCITY SENSING LIMIT
BOTTOM
LOWER VELOCITY SENSING LIMIT
07/11/2003
05/25/2004
DEPTH, IN FEET
0
5
10
15
20
25
30
35
0
250
500
750
1000
DISTANCE ALONG CROSS SECTION, IN FEET

Figure A.23

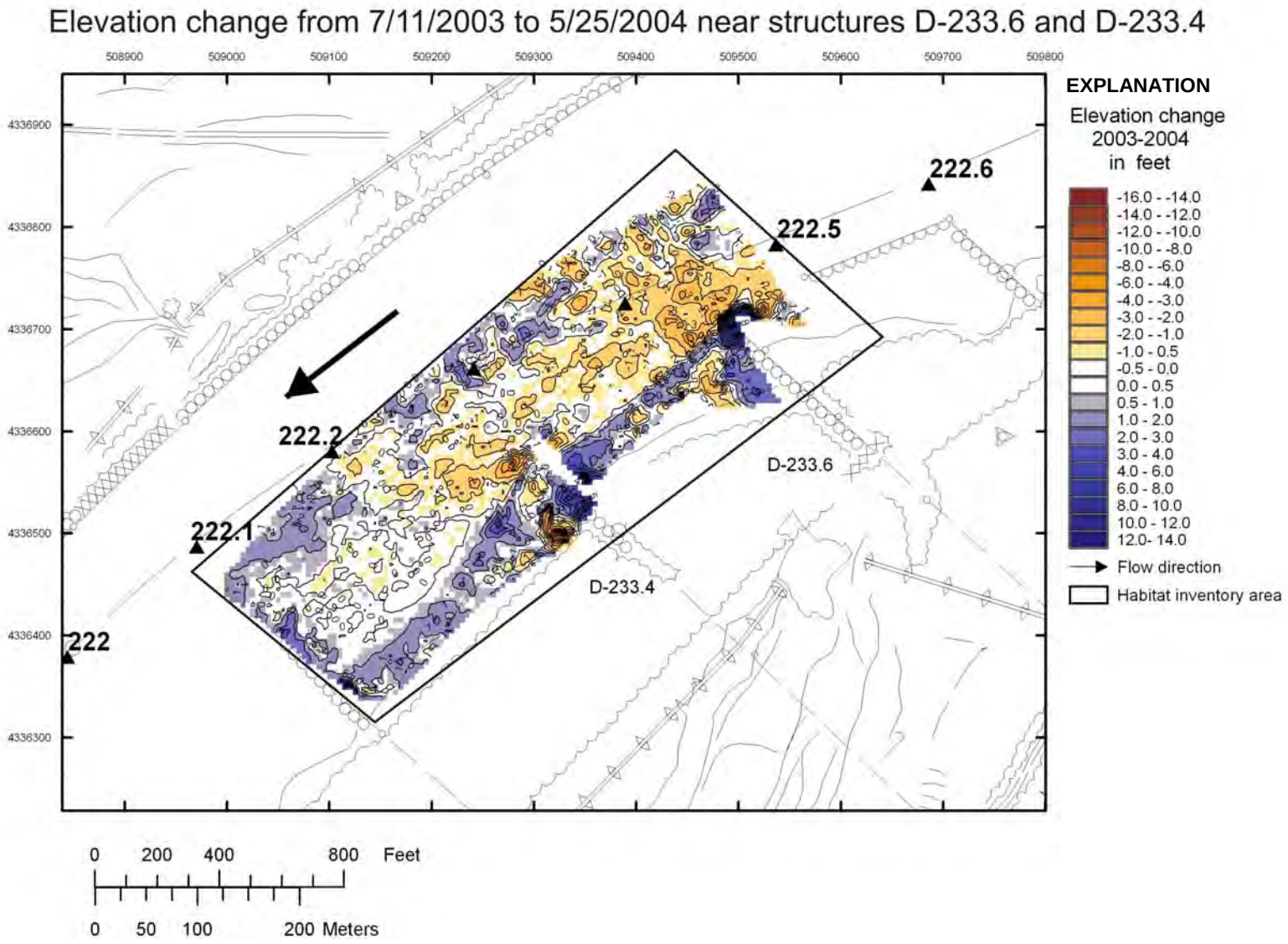
Elevation change from 7/11/2003 to 5/25/2004 near structures D-233.6 and D-233.4
508900
509000
509100
509200
509300
509400
509500
509600
509700
509800
4336900
4336800
4336700
4336600
4336500
4336400
4336300
222.6
222.5
222.2
222.1
222
D-233.6
D-233.4
EXPLANATION
Elevation change 2003-2004 in feet
-16.0 - -14.0
-14.0 - -12.0
-12.0 - -10.0
-10.0 - -8.0
-8.0 - -6.0
-6.0 - -4.0
-4.0 - -3.0
-3.0 - -2.0
-2.0 - -1.0
-1.0 - 0.5
-0.5 - 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 6.0
6.0 - 8.0
8.0 - 10.0
10.0 - 12.0
12.0- 14.0
Flow direction
Habitat inventory area
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.24

A.25 Shallow Water Habitat Assessment, Lower Missouri River

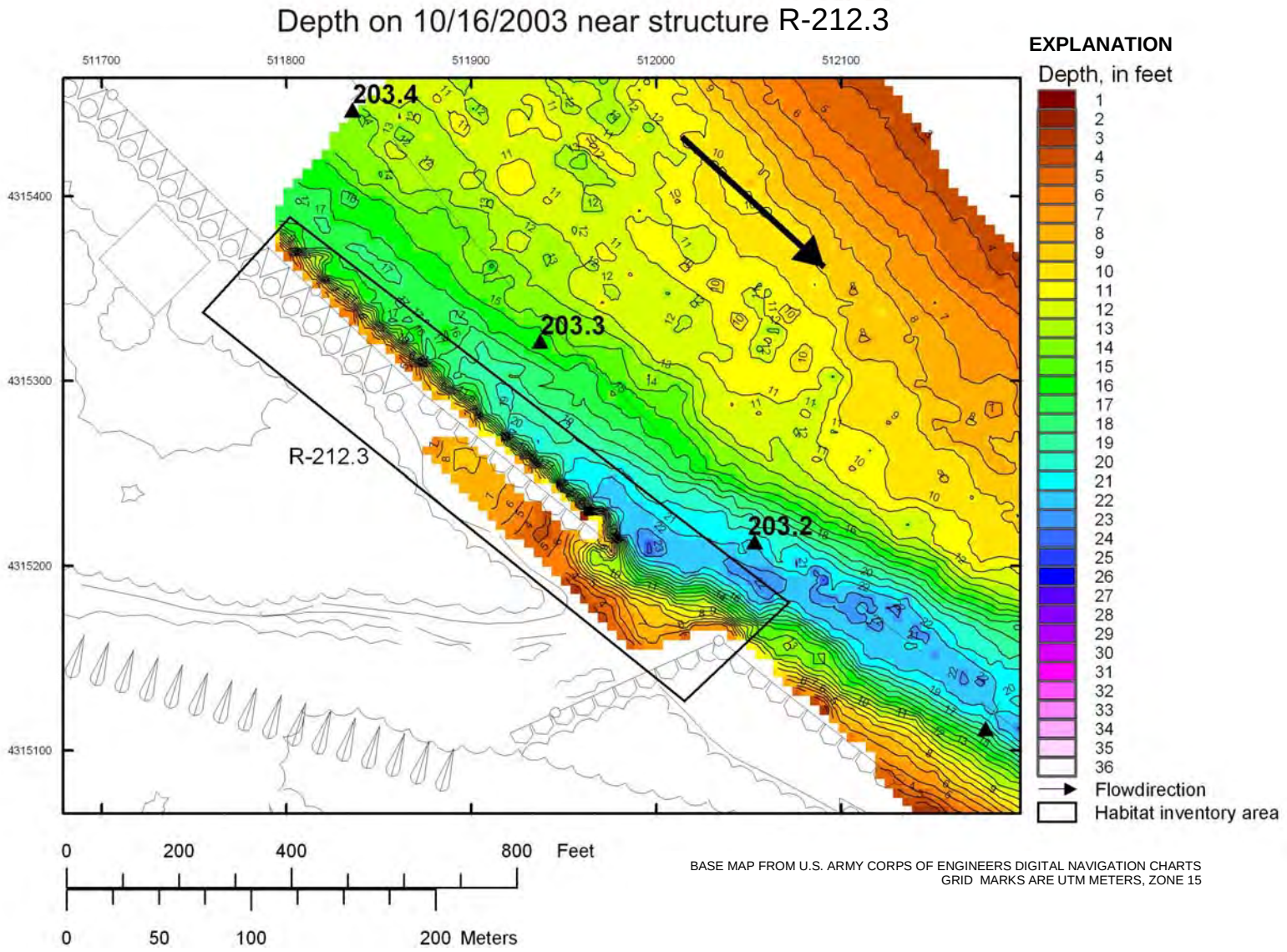

Figure A.25

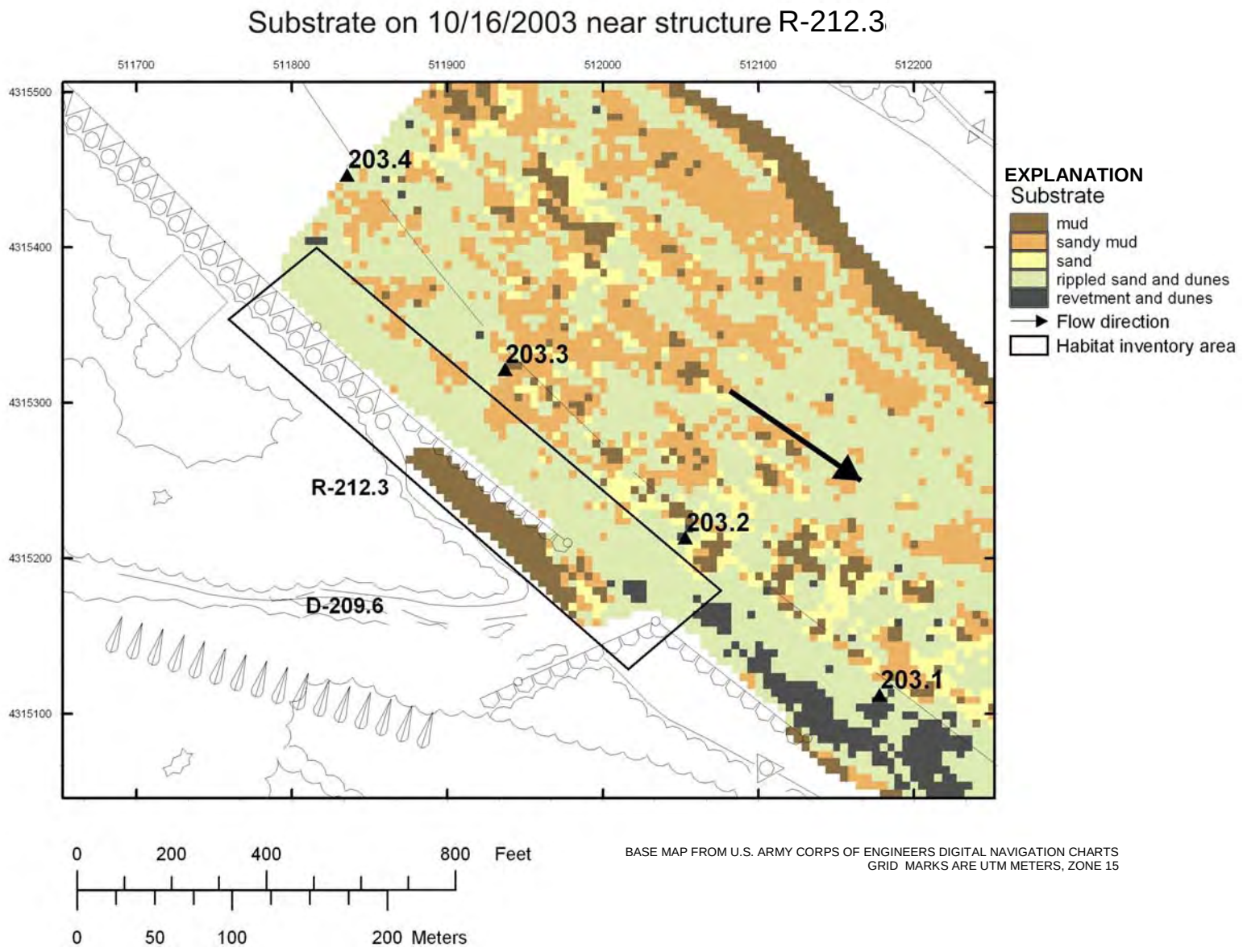
Substrate on 10/16/2003 near structure R-212.3
511700
511800
511900
512000
512100
512200
4315500
4315400
4315300
4315200
4315100
203.4
203.3
203.2
203.1
R-212.3
D-209.6
EXPLANATION
Substrate
mud
sandy mud
sand
rippled sand and dunes
revetment and dunes
Flow direction
Habitat inventory area
0
200
400
800
Feet
0
50
100
200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.26

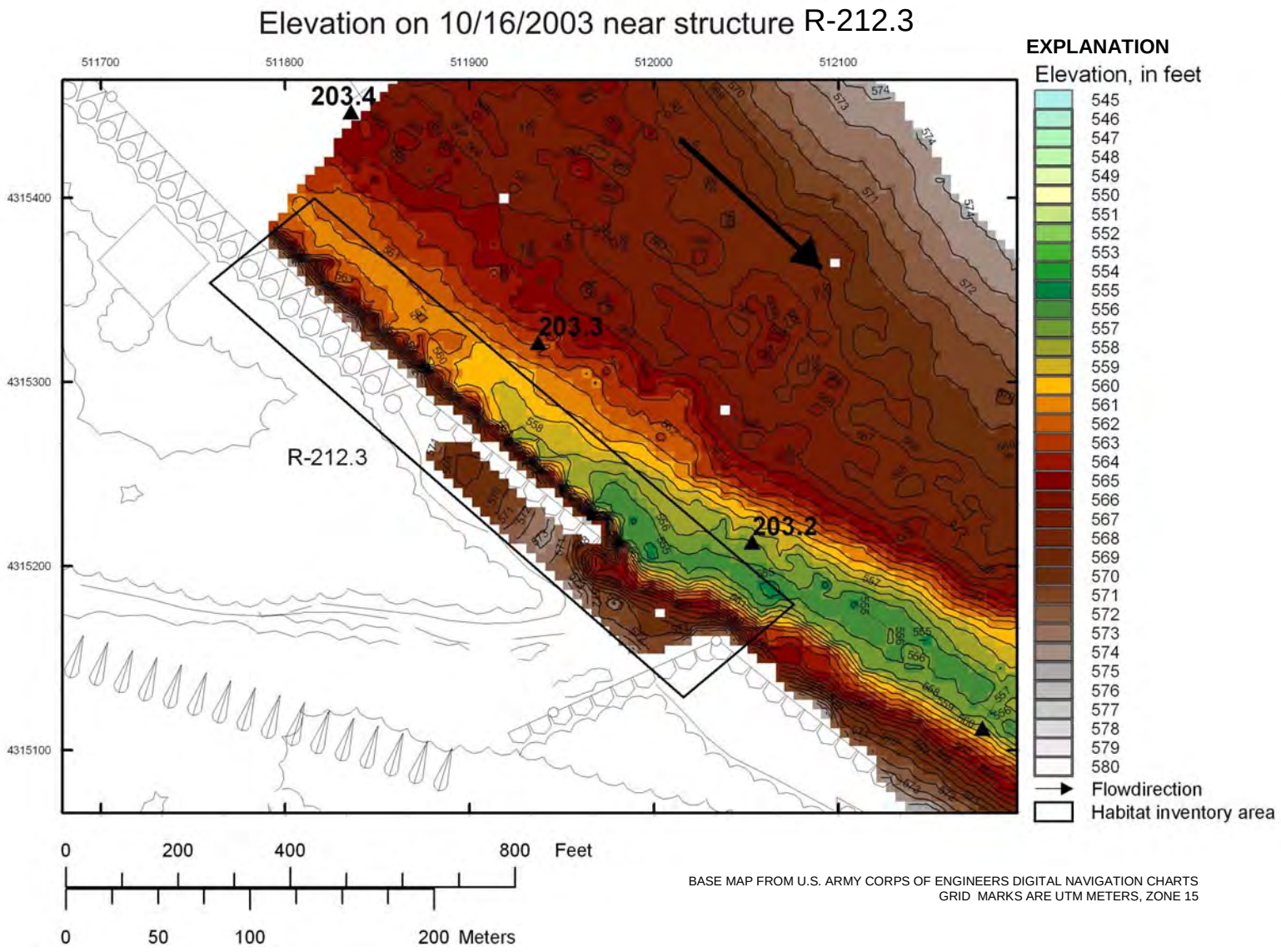
Elevation on 10/16/2003 near structure R-212.3
511700
511800
511900
512000
512100
4315400
4315300
4315200
4315100
203.4
203.3
203.2
R-212.3
EXPLANATION
Elevation, in feet
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
Flowdirection
Habitat inventory area
0
200
400
800 Feet
0
50
100
200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.27

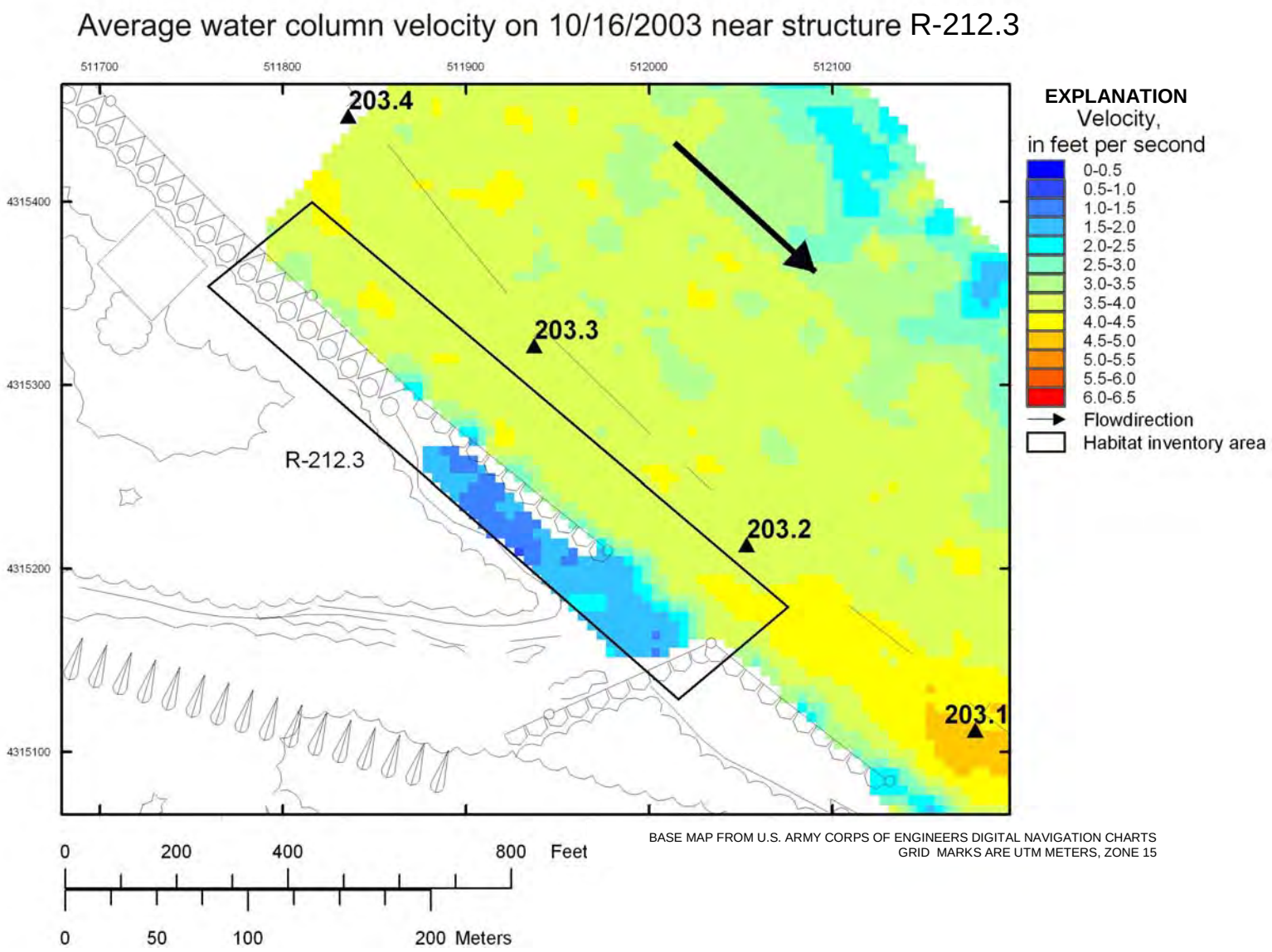
Average water column velocity on 10/16/2003 near structure R-212.3
511700
511800
511900
512000
512100
4315400
4315300
4315200
4315100
203.4
203.3
203.2
203.1
R-212.3
EXPLANATION
Velocity,
in feet per second
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
Flowdirection
Habitat inventory area
0 200 400 800 Feet
0 50 100 200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.28

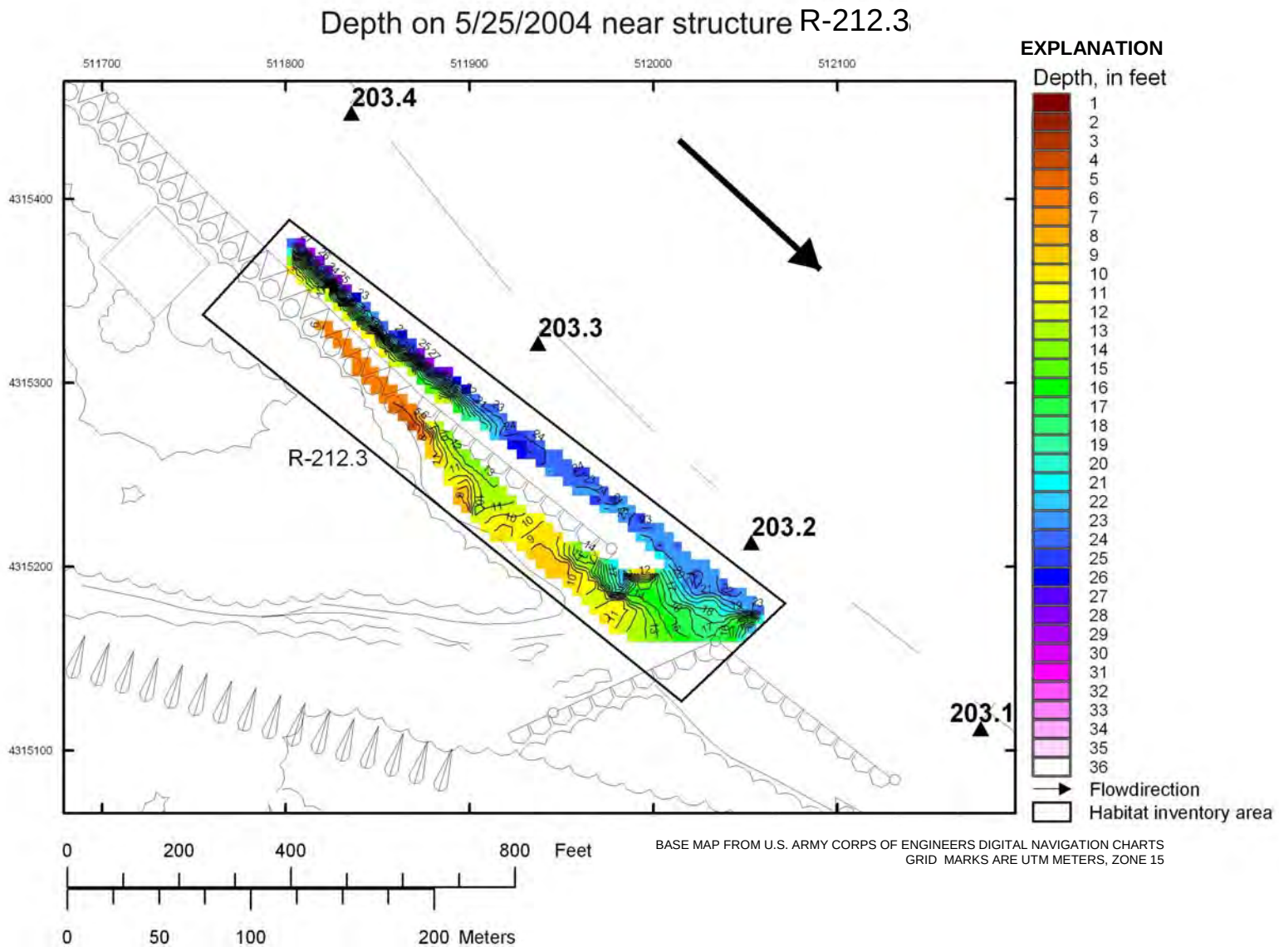
Depth on 5/25/2004 near structure R-212.3
511700
511800
511900
512000
512100
4315400
4315300
4315200
4315100
203.4
203.3
203.2
203.1
R-212.3
EXPLANATION
Depth, in feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
Flowdirection
Habitat inventory area
0
200
400
800
Feet
0
50
100
200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.29

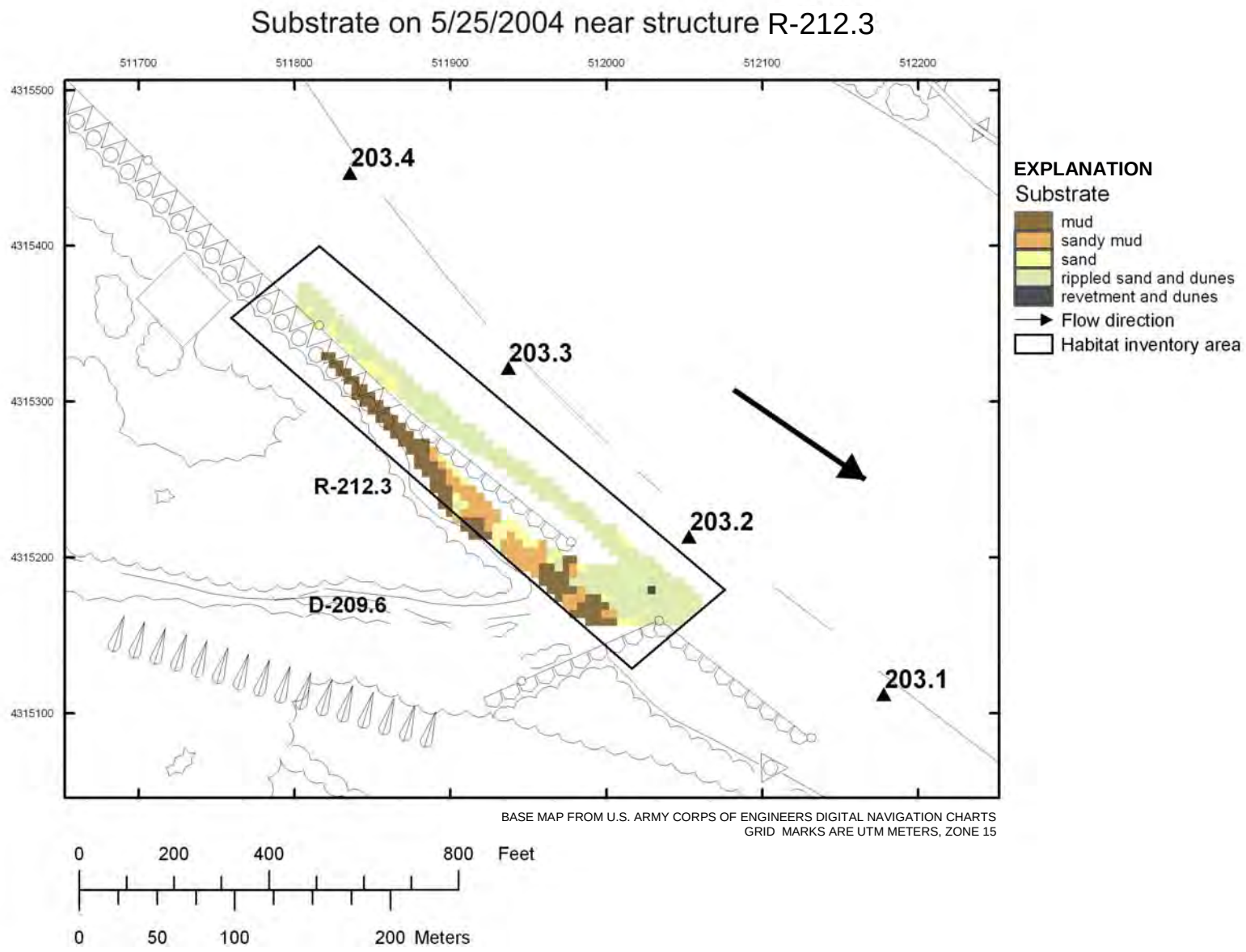
Substrate on 5/25/2004 near structure R-212.3
511700
511800
511900
512000
512100
512200
4315500
4315400
4315300
4315200
4315100
203.4
203.3
203.2
203.1
R-212.3
D-209.6
EXPLANATION
Substrate
mud
sandy mud
sand
rippled sand and dunes
revetment and dunes
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.30

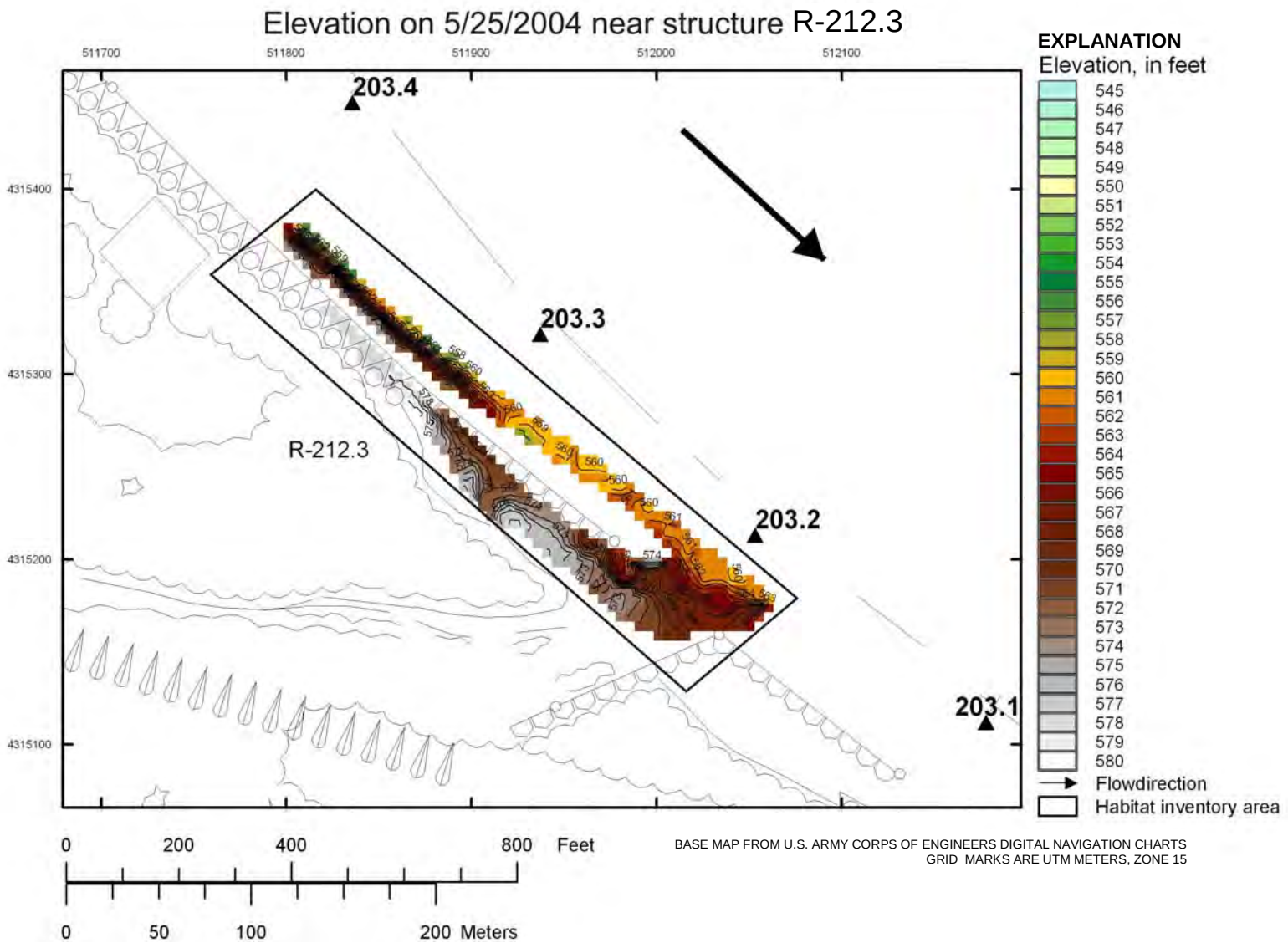
Elevation on 5/25/2004 near structure R-212.3
511700
511800
511900
512000
512100
4315400
4315300
4315200
4315100
203.4
203.3
203.2
203.1
R-212.3
EXPLANATION
Elevation, in feet
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
Flowdirection
Habitat inventory area
0 200 400 800 Feet
0 50 100 200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.31

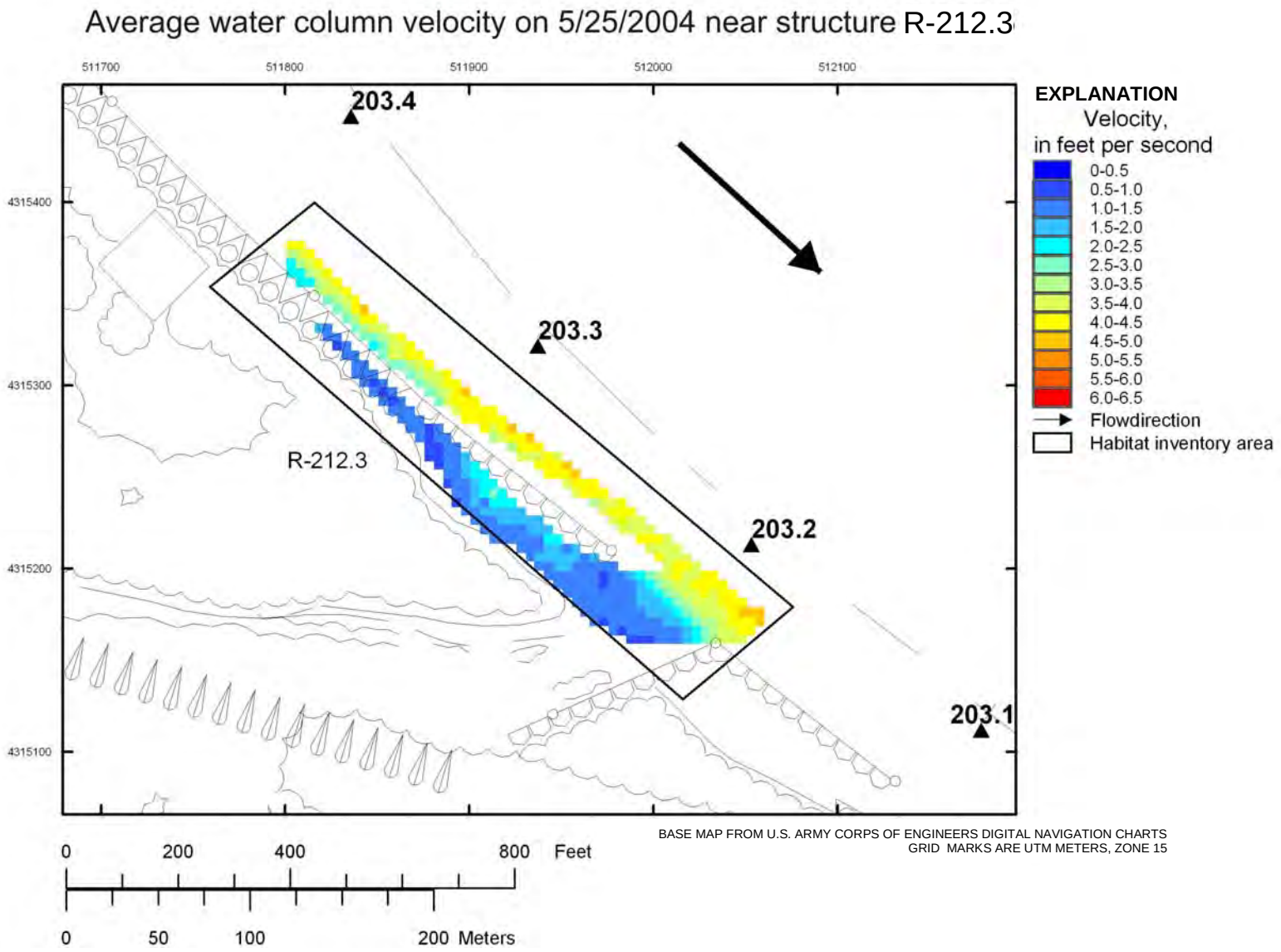
Average water column velocity on 5/25/2004 near structure R-212.3
511700
511800
511900
512000
512100
4315400
4315300
4315200
4315100
203.4
203.3
203.2
203.1
R-212.3
EXPLANATION
Velocity,
in feet per second
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
Flowdirection
Habitat inventory area
0
200
400
800
Feet
0
50
100
200
Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.32

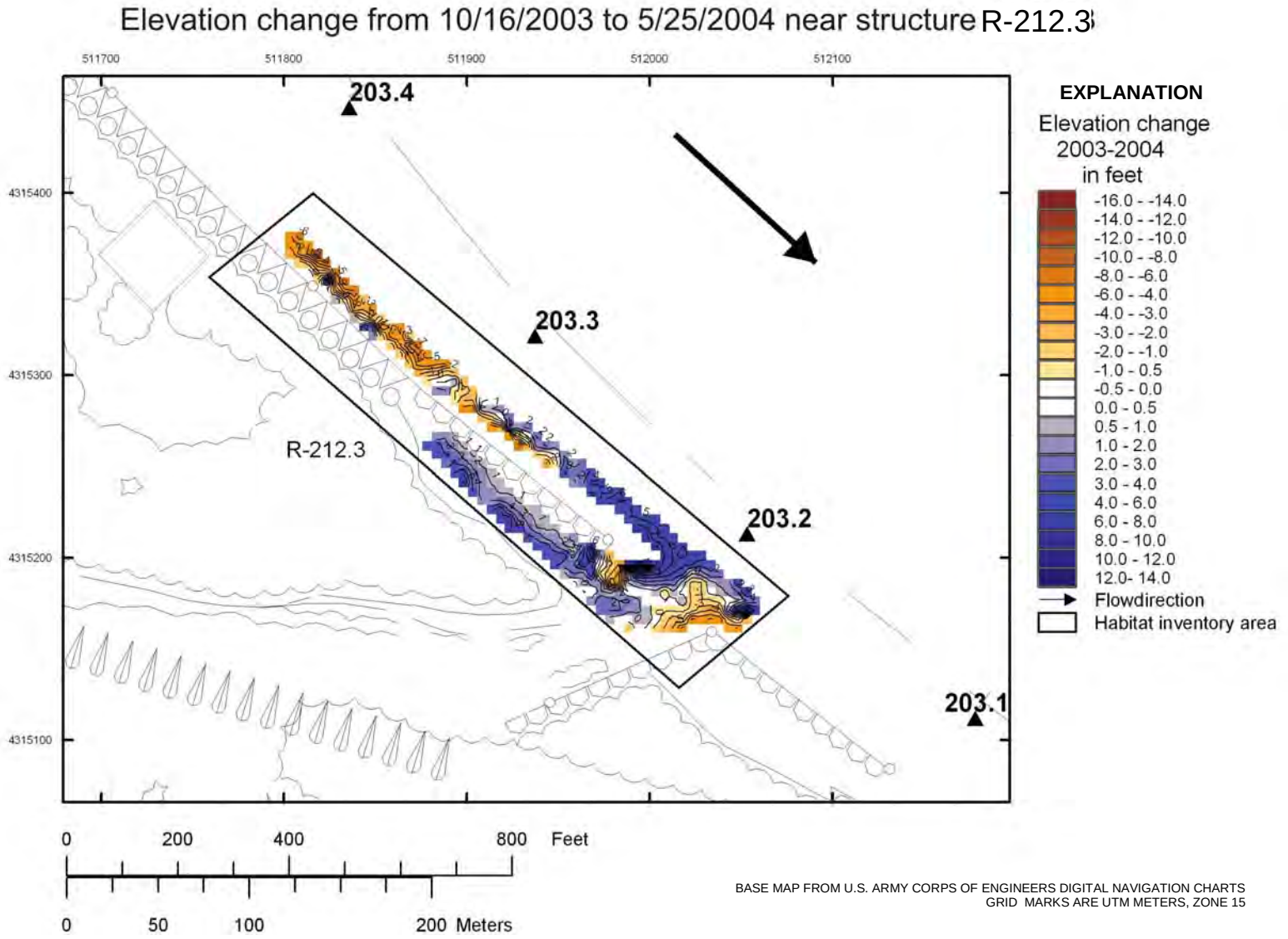
Elevation change from 10/16/2003 to 5/25/2004 near structure R-212.3
511700
511800
511900
512000
512100
4315400
4315300
4315200
4315100
203.4
203.3
203.2
203.1
R-212.3
EXPLANATION
Elevation change 2003-2004 in feet
-16.0 - -14.0
-14.0 - -12.0
-12.0 - -10.0
-10.0 - -8.0
-8.0 - -6.0
-6.0 - -4.0
-4.0 - -3.0
-3.0 - -2.0
-2.0 - -1.0
-1.0 - 0.5
-0.5 - 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 6.0
6.0 - 8.0
8.0 - 10.0
10.0 - 12.0
12.0- 14.0
Flowdirection
Habitat inventory area
0 200 400 800 Feet
0 50 100 200 Meters
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15

Figure A.33

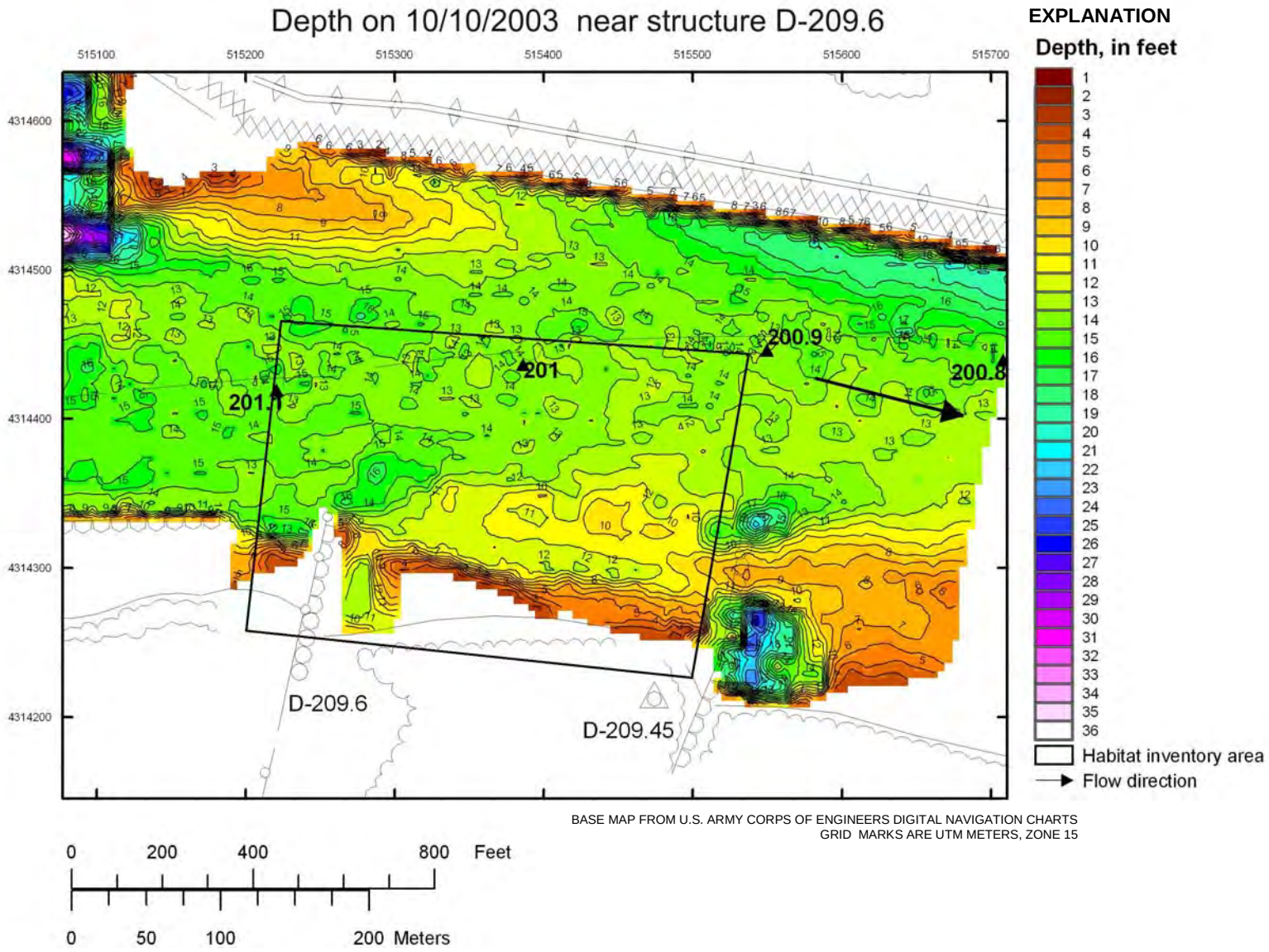
Depth on 10/10/2003 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314600
4314500
4314400
4314300
4314200
201.1
201
200.9
200.8
D-209.6
D-209.45
EXPLANATION
Depth, in feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
Habitat inventory area
Flow direction
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
200
400
800
Feet
0
50
100
200 Meters

Figure A.34

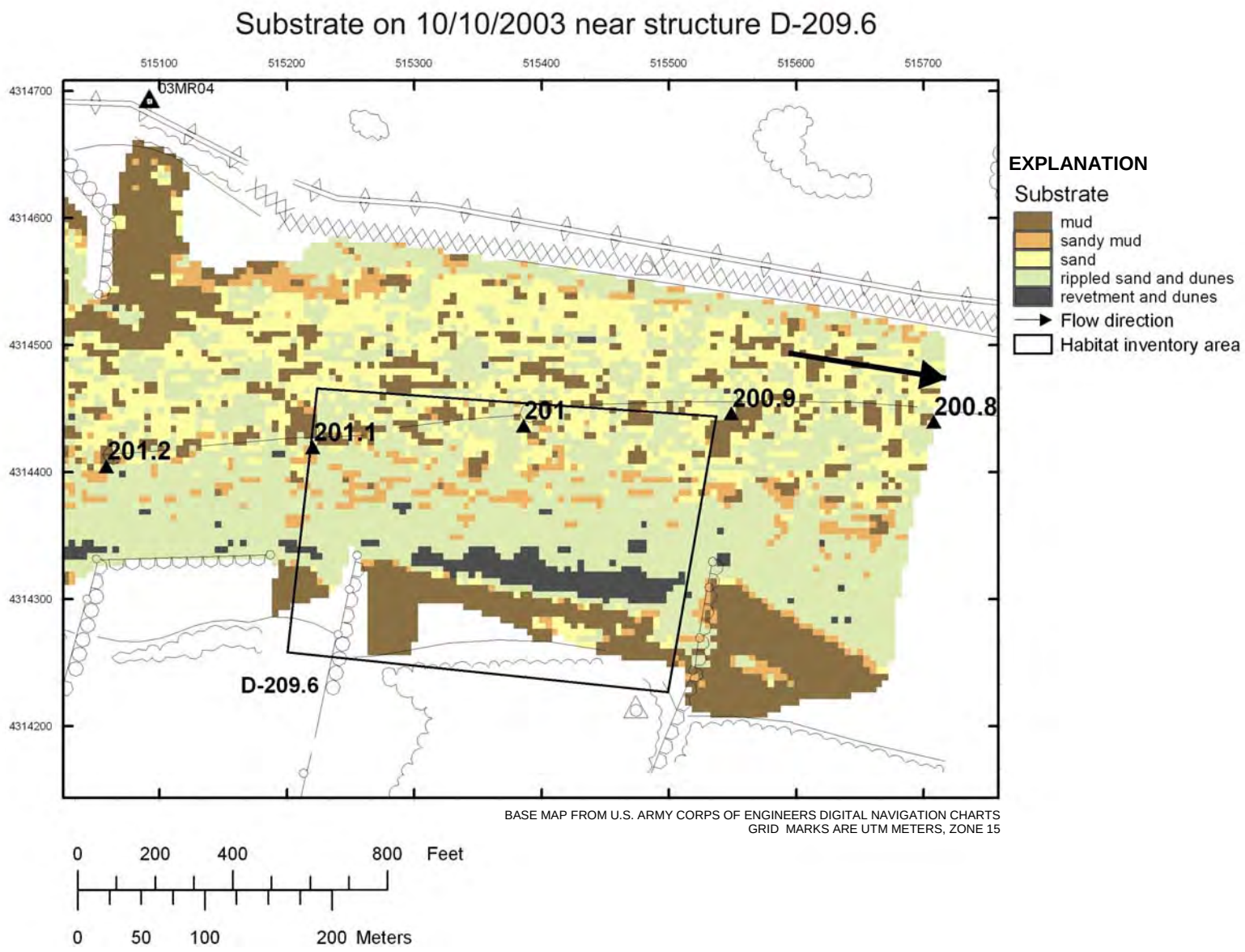
Substrate on 10/10/2003 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314700
4314600
4314500
4314400
4314300
4314200
03MR04
201.2
201.1
201
200.9
200.8
D-209.6
EXPLANATION
Substrate
mud
sandy mud
sand
rippled sand and dunes
revetment and dunes
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.35

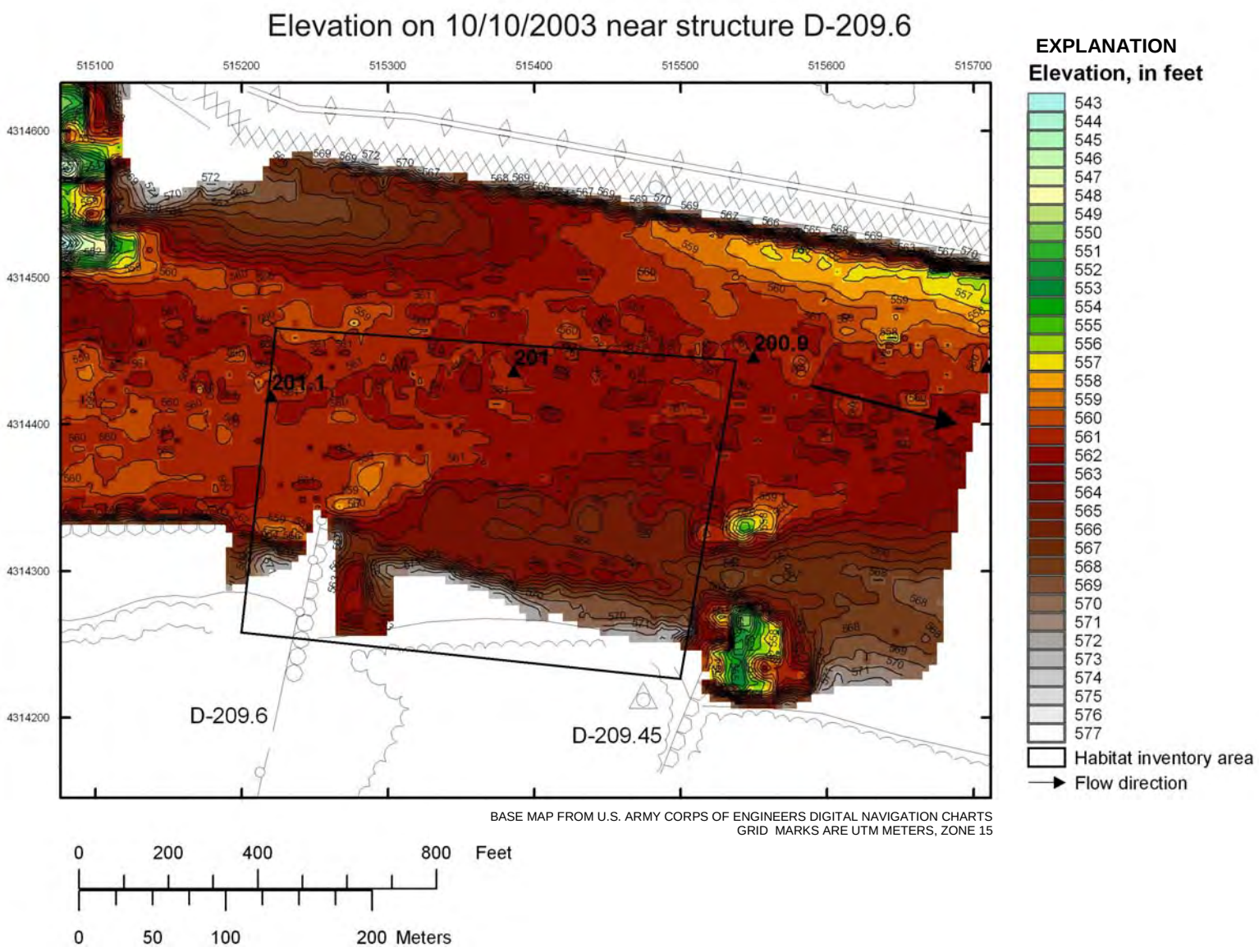
Elevation on 10/10/2003 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314600
4314500
4314400
4314300
4314200
201.1
201
200.9
D-209.6
D-209.45
EXPLANATION
Elevation, in feet
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
Habitat inventory area
Flow direction
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
200
400
800
Feet
0
50
100
200 Meters

Figure A.36

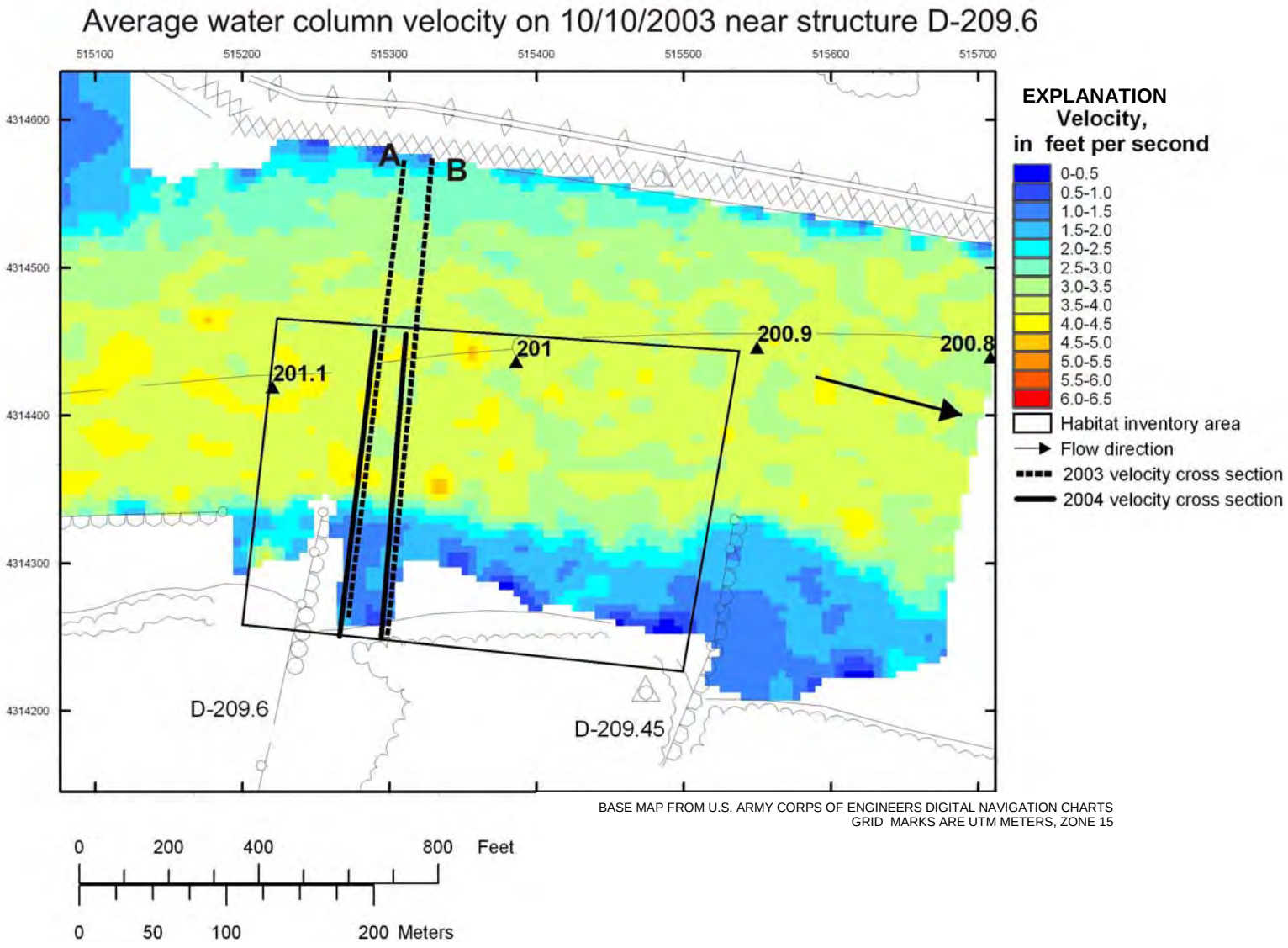
Average water column velocity on 10/10/2003 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314600
4314500
4314400
4314300
4314200
A
B
201.1
201
200.9
200.8
D-209.6
D-209.45
EXPLANATION
Velocity,
in feet per second
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
Habitat inventory area
Flow direction
2003 velocity cross section
2004 velocity cross section
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
200
400
800
Feet
0
50
100
200
Meters

Figure A.37

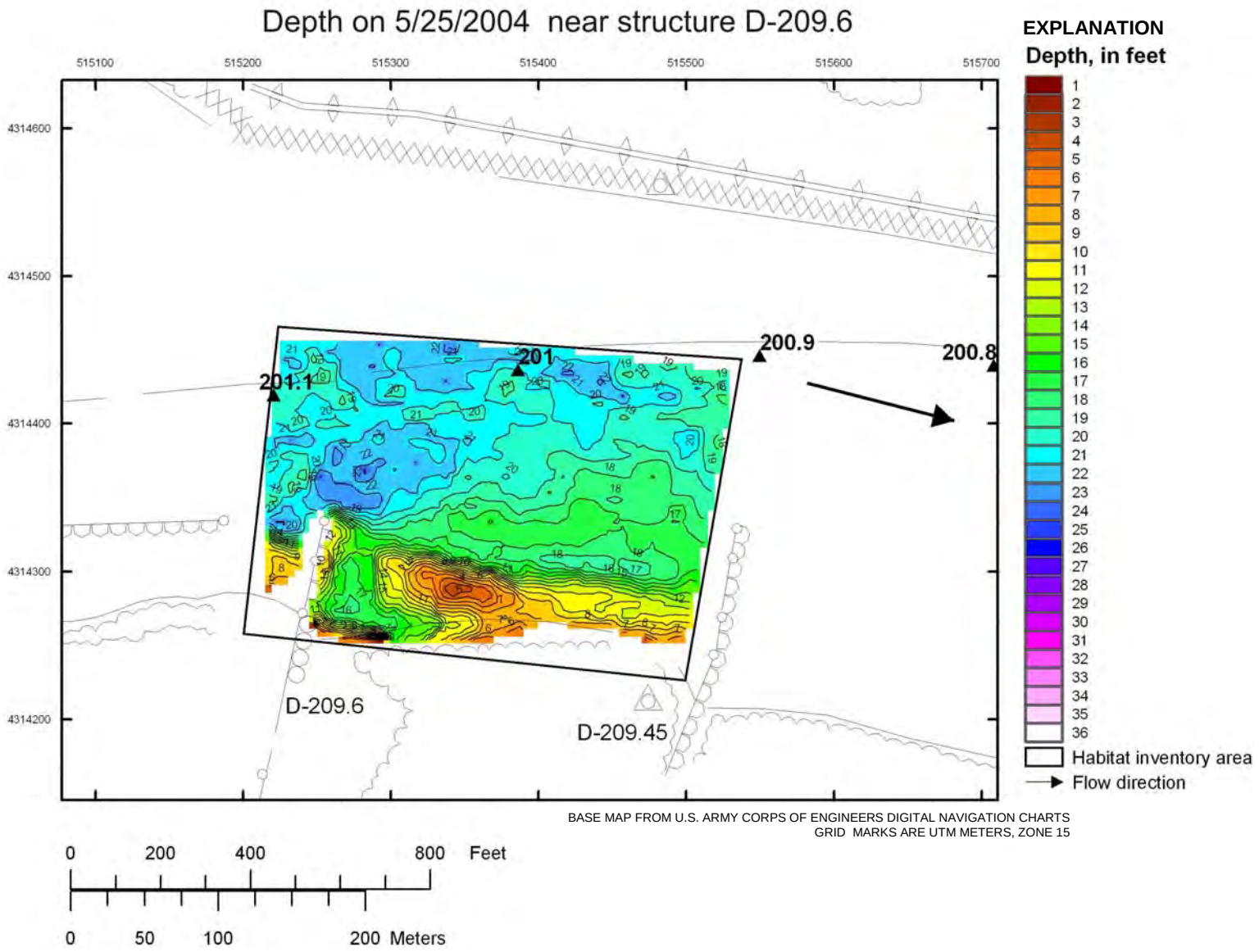
Depth on 5/25/2004 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314600
4314500
4314400
4314300
4314200
201.1
201
200.9
200.8
D-209.6
D-209.45
EXPLANATION
Depth, in feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
Habitat inventory area
Flow direction
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
200
400
800
Feet
0
50
100
200
Meters

Figure A.38

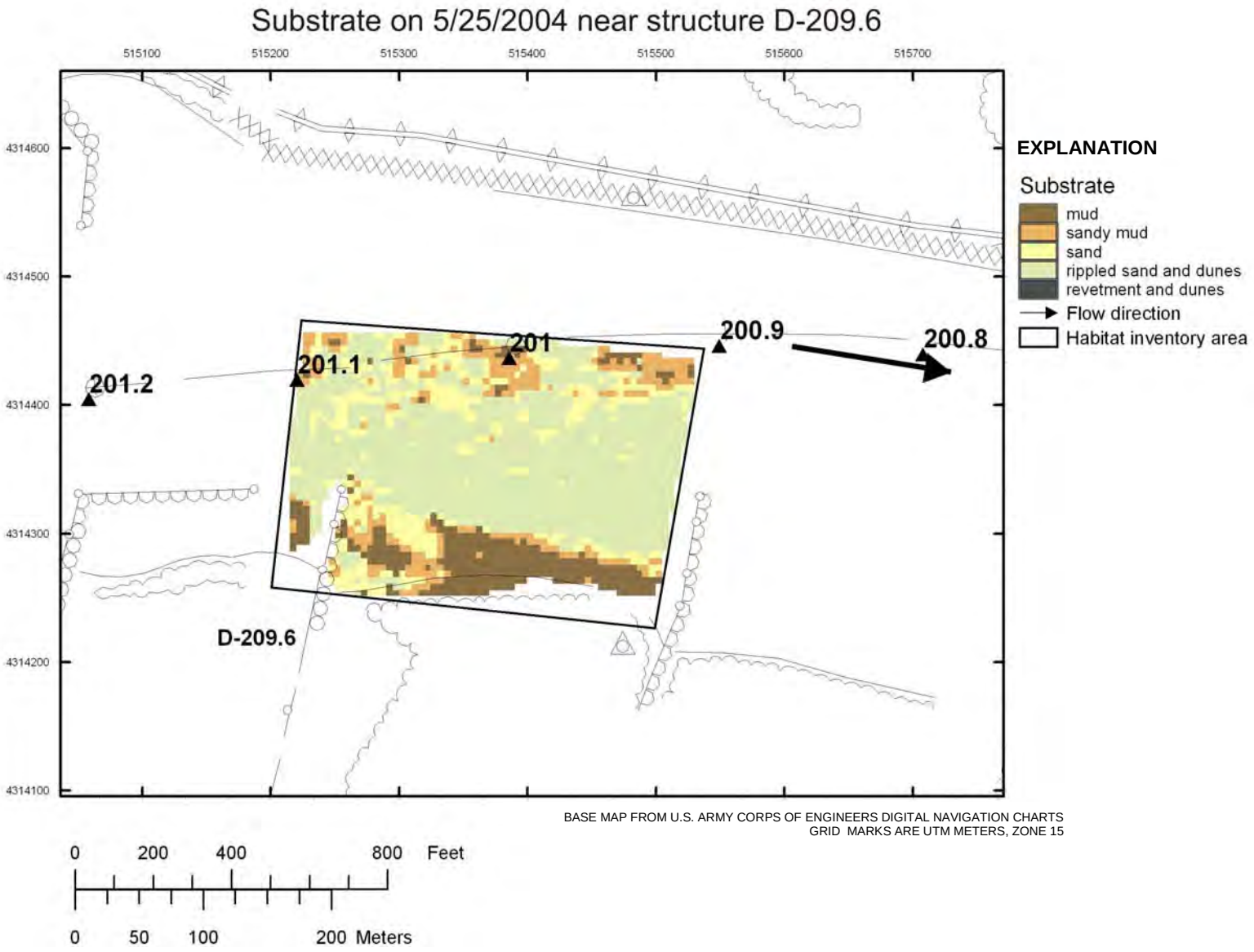
Substrate on 5/25/2004 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314600
4314500
4314400
4314300
4314200
4314100
201.2
201.1
201
200.9
200.8
D-209.6
EXPLANATION
Substrate
mud
sandy mud
sand
rippled sand and dunes
revetment and dunes
Flow direction
Habitat inventory area
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.39

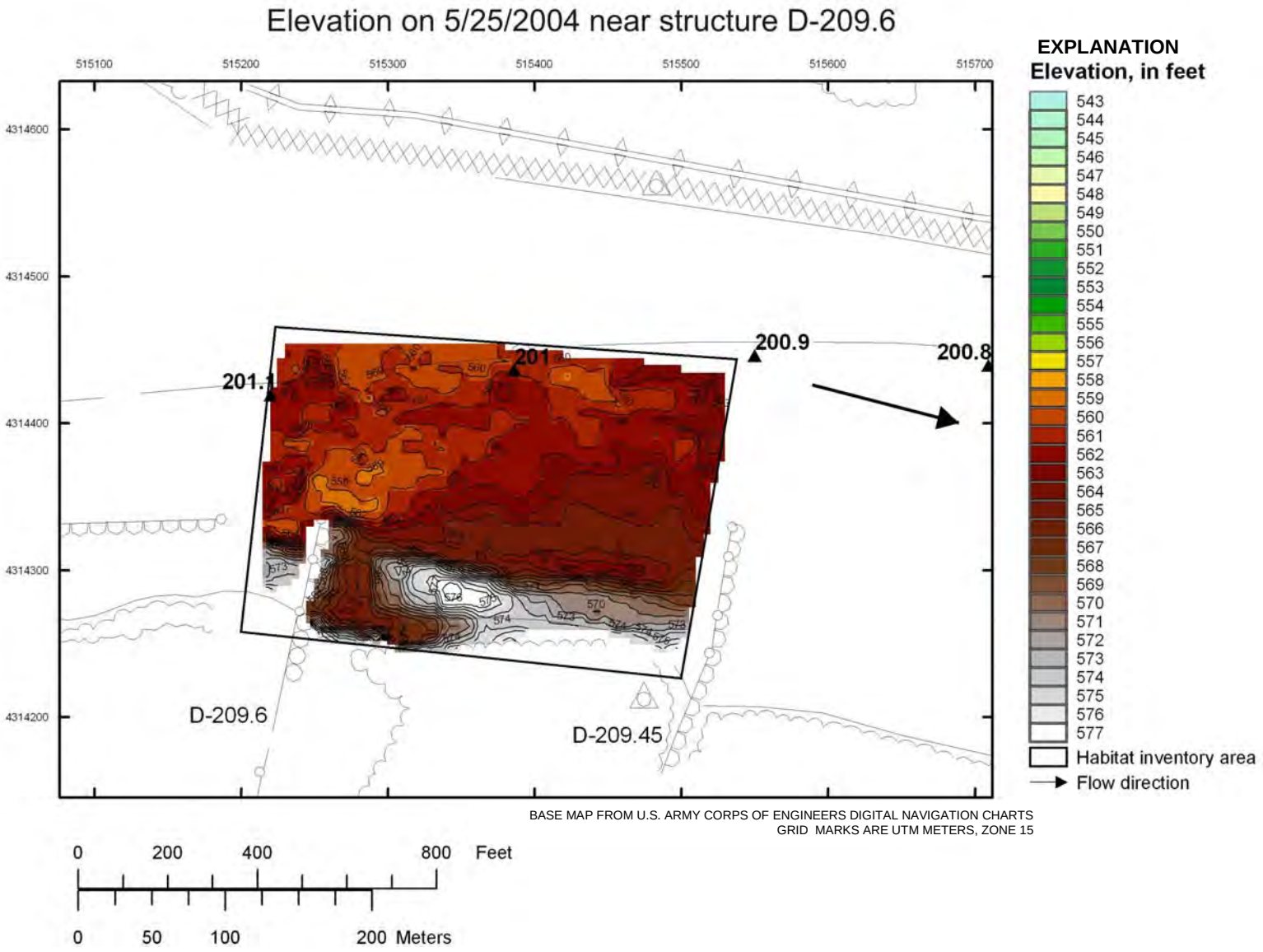
Elevation on 5/25/2004 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314600
4314500
4314400
4314300
4314200
201.1
201
200.9
200.8
D-209.6
D-209.45
EXPLANATION
Elevation, in feet
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
Habitat inventory area
Flow direction
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0
200
400
800
Feet
0
50
100
200 Meters

Figure A.40

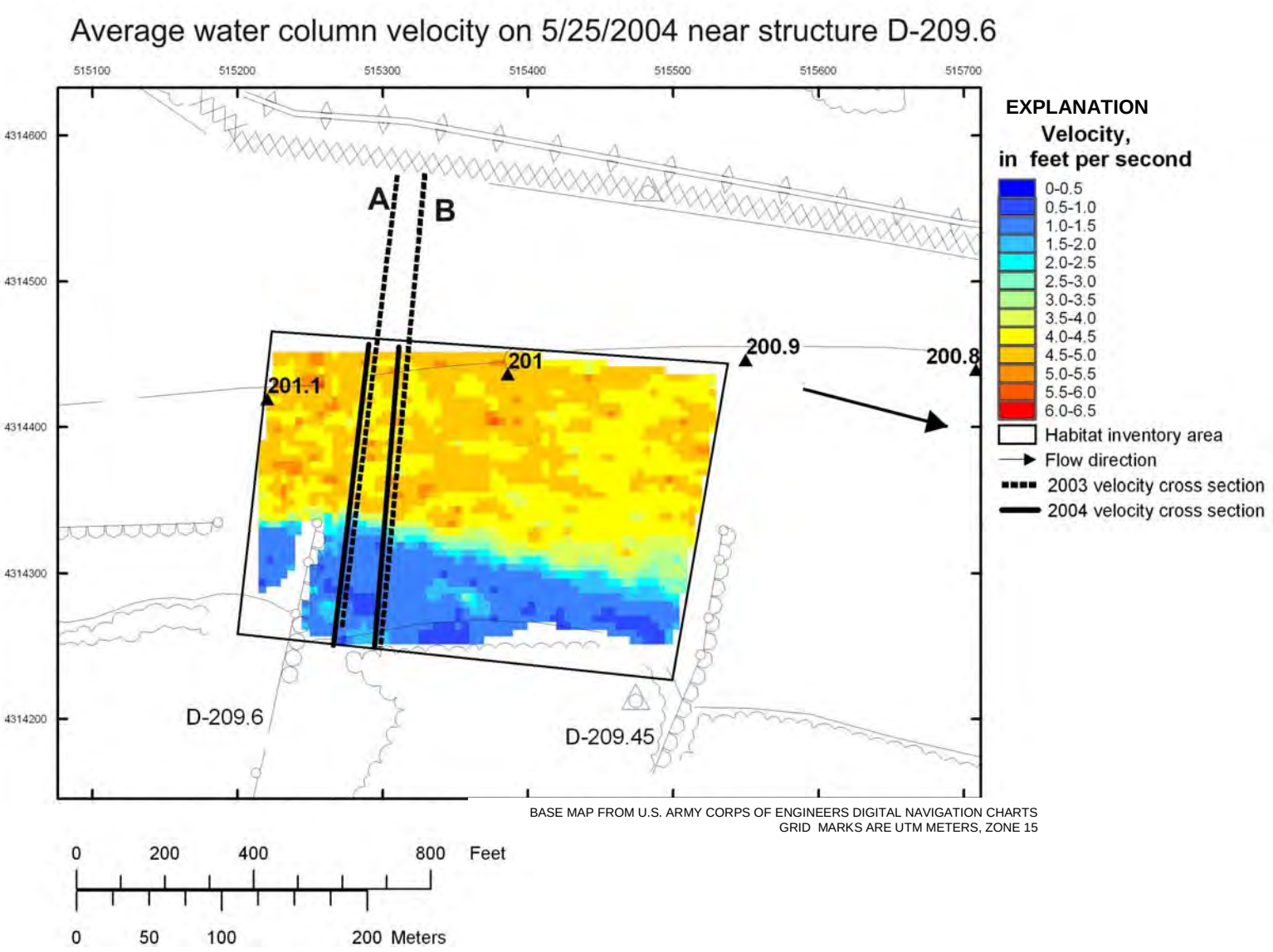
Average water column velocity on 5/25/2004 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314600
4314500
4314400
4314300
4314200
A
B
201.1
201
200.9
200.8
D-209.6
D-209.45
EXPLANATION
Velocity, in feet per second
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
Habitat inventory area
Flow direction
2003 velocity cross section
2004 velocity cross section
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.41

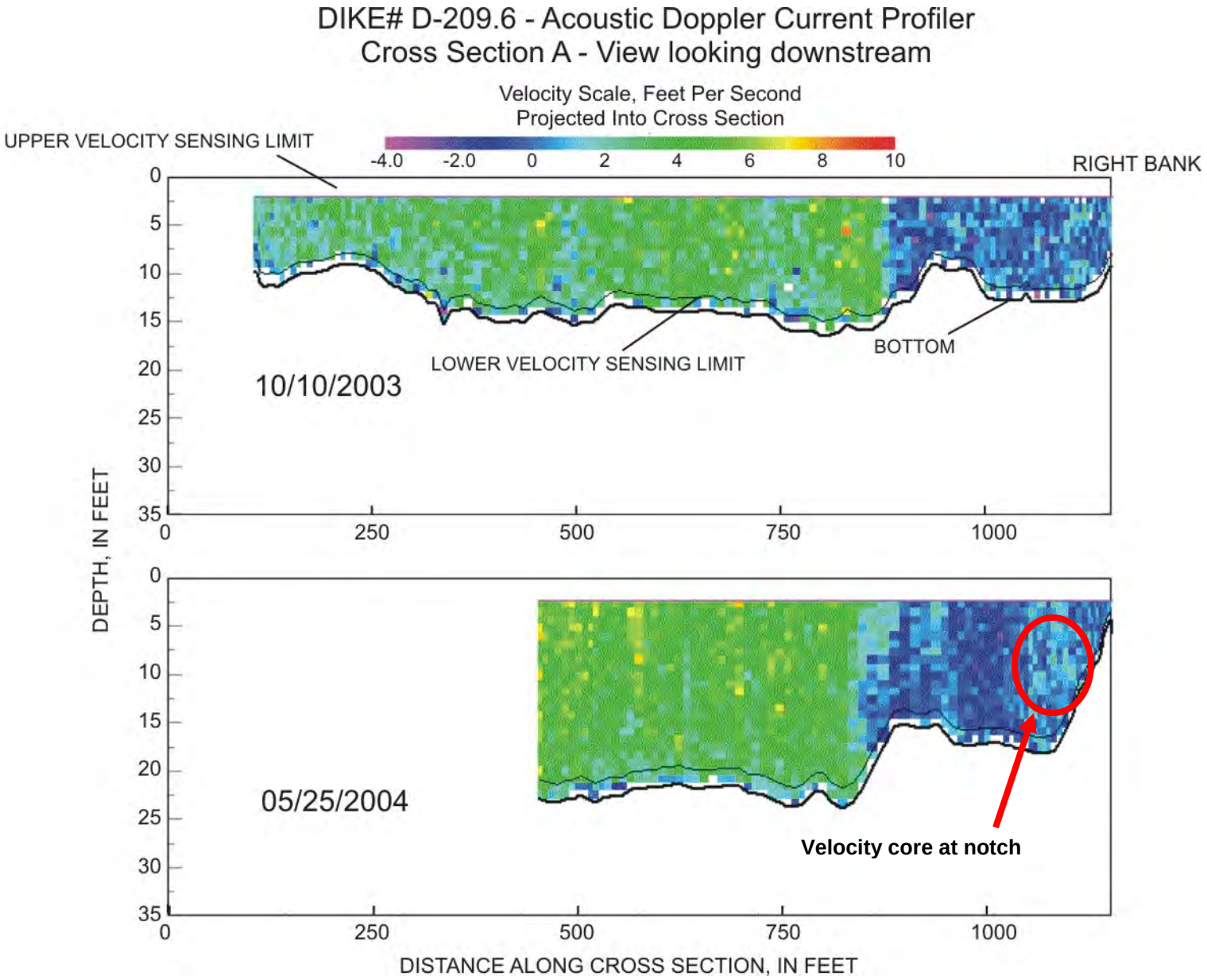
DIKE# D-209.6 - Acoustic Doppler Current Profiler
Cross Section A - View looking downstream
Velocity Scale, Feet Per Second
Projected Into Cross Section
-4.0
-2.0
0
2
4
6
8
10
UPPER VELOCITY SENSING LIMIT
RIGHT BANK
LOWER VELOCITY SENSING LIMIT
BOTTOM
10/10/2003
05/25/2004
Velocity core at notch
DEPTH, IN FEET
DISTANCE ALONG CROSS SECTION, IN FEET
0
5
10
15
20
25
30
35
0
250
500
750
1000

Figure A.42

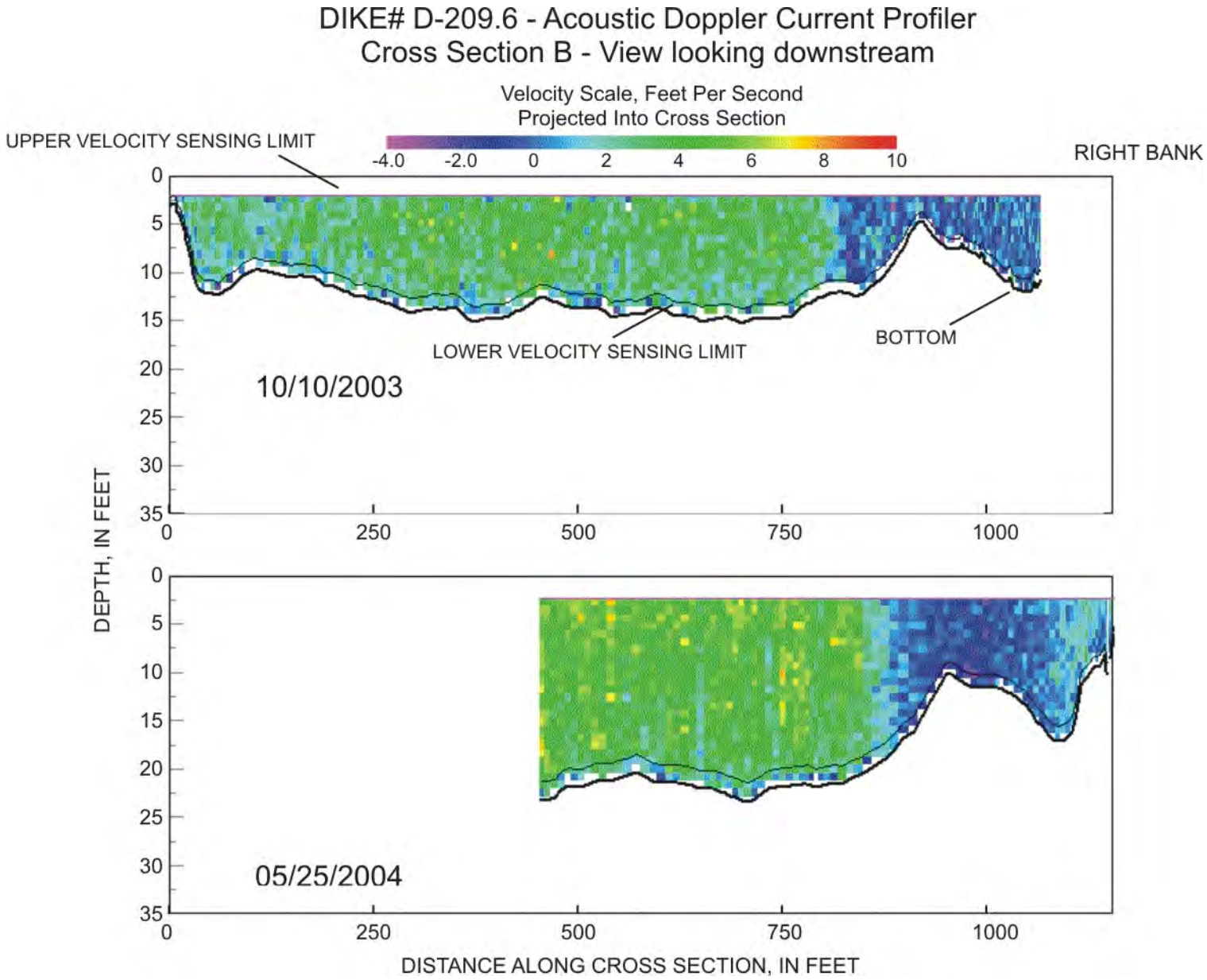
DIKE# D-209.6 - Acoustic Doppler Current Profiler
Cross Section B - View looking downstream
Velocity Scale, Feet Per Second
Projected Into Cross Section
-4.0
-2.0
0
2
4
6
8
10
UPPER VELOCITY SENSING LIMIT
RIGHT BANK
LOWER VELOCITY SENSING LIMIT
BOTTOM
10/10/2003
05/25/2004
DEPTH, IN FEET
DISTANCE ALONG CROSS SECTION, IN FEET
0
5
10
15
20
25
30
35
0
250
500
750
1000

Figure A.43

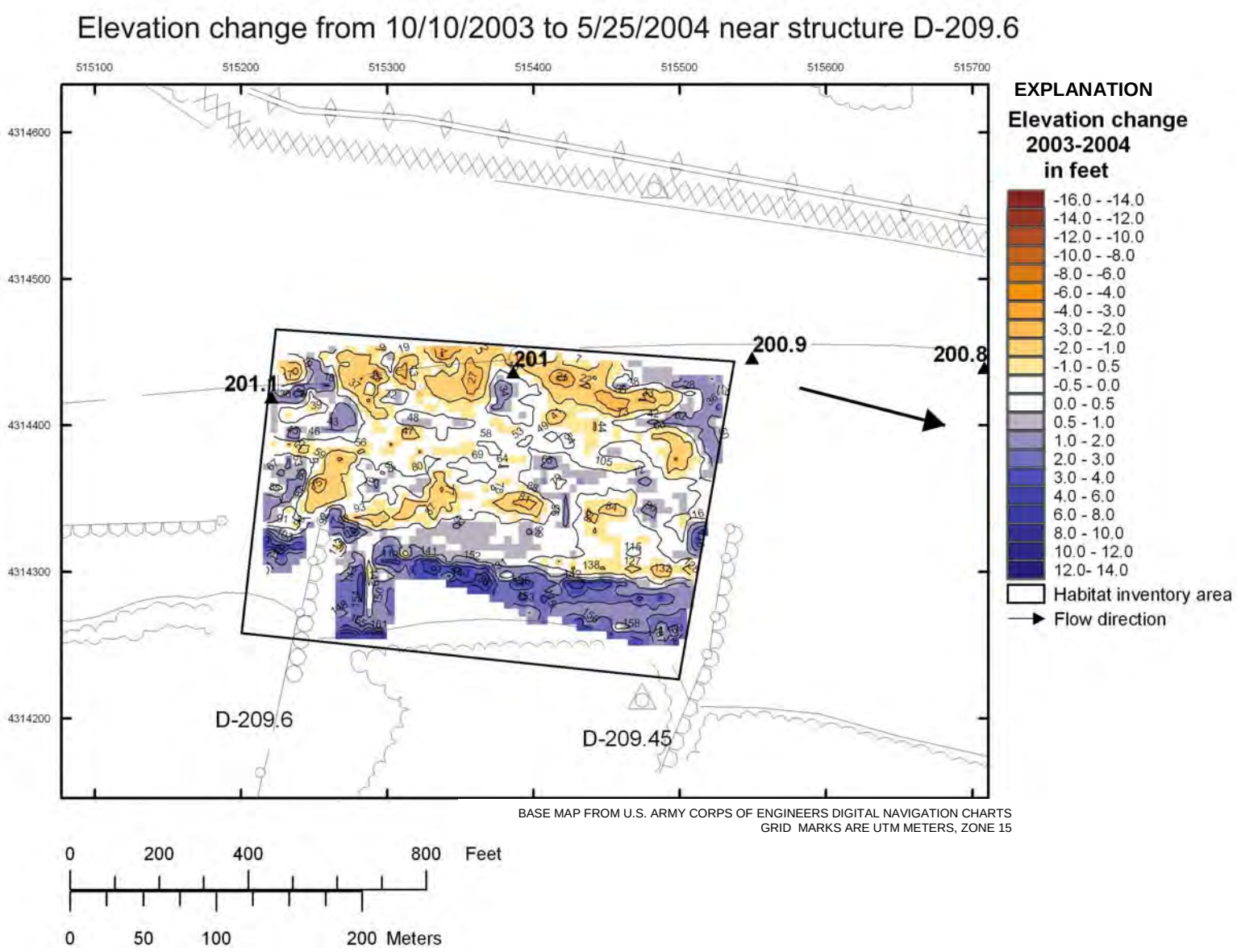
Elevation change from 10/10/2003 to 5/25/2004 near structure D-209.6
515100
515200
515300
515400
515500
515600
515700
4314600
4314500
4314400
4314300
4314200
201.1
201
200.9
200.8
D-209.6
D-209.45
EXPLANATION
Elevation change 2003-2004 in feet
-16.0 - -14.0
-14.0 - -12.0
-12.0 - -10.0
-10.0 - -8.0
-8.0 - -6.0
-6.0 - -4.0
-4.0 - -3.0
-3.0 - -2.0
-2.0 - -1.0
-1.0 - 0.5
-0.5 - 0.0
0.0 - 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 6.0
6.0 - 8.0
8.0 - 10.0
10.0 - 12.0
12.0- 14.0
Habitat inventory area
Flow direction
BASE MAP FROM U.S. ARMY CORPS OF ENGINEERS DIGITAL NAVIGATION CHARTS
GRID MARKS ARE UTM METERS, ZONE 15
0 200 400 800 Feet
0 50 100 200 Meters

Figure A.44