Susitna-Watana Hydroelectric Project

(FERC No. 14241)

Groundwater Study

Study Plan Section 7.5

Upwelling Broad-Scale Mapping of the Middle Susitna River Technical Memorandum

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

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LIST OF ACRONYMS AND SCIENTIFIC LABELS

ABBREVIATION	DEFINITION
AEA	Alaska Energy Authority
APA	Alaska Power Authority
FA	Focus Area
FERC	Federal Energy Regulatory Commission
FLIR	Forward Looking Infrared
GIS	Geographic Information System
GPS	Global Positioning System
GW/SW	Groundwater/Surface Water
HSC	Habitat Suitability Criteria
IFS	Fish and Aquatics Instream Flow Study 8.5
ISR	Initial Study Report
MR	Middle Susitna River Segment, PRM 187.1 to PRM 102.4
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project, FERC No. 14241
RIFS	Riparian Instream Flow Study 8.6
RM	River Mile or Historic River Mile
RMSE	Root-Mean Square Error
RSP	Revised Study Plan
SIR	2014-2015 Study Implementation Report
TIR	Thermal Infrared Remote
TM	Technical Memorandum
USR	Updated Study Report
VHG	Vertical Hydraulic Gradient

1. INTRODUCTION

On December 14, 2012, Alaska Energy Authority (AEA) filed its Revised Study Plan (RSP) with the Federal Energy Regulatory Commission (FERC or Commission) for the Susitna-Watana Hydroelectric Project, FERC Project No. 14241 (Project), which included 58 individual study plans (AEA 2012). Included within the RSP was the Groundwater Study (GW), Section 7.5. On April 1, 2013 SPD, FERC approved the RSP with recommendations. As established in Study Plan Section 7.5[1], the Groundwater Study is focused on providing an overall understanding of groundwater/surface water (GW/SW) interactions at both the watershed- and local-scales. Study Plan Section 7.5 also describes the study methods that would be used to evaluate Project effects on GW/SW interactions and how those influences may impact riparian and aquatic habitats in the Susitna River.

AEA filed the Initial Study Report Parts A, B, and C on June 3, 2014. Study 7.5 ISR Part A of the Initial Study Report (ISR) details the development of the Groundwater Study from the Revised Study Plan (RSP) in 2012, through the end of the 2013 study season. Study 7.5 ISR Part C, Section 7 sets forth AEA's plan and schedule, at that time, for completing this study and meeting the objectives of the Study Plan. Two Technical Memoranda (TM) were prepared and filed on September 30, 2014 that presented results of preliminary groundwater (GW)/surface water (SW) analysis related to Groundwater Study Objective 5 that pertains to the Riparian Instream Flow Study (RIFS) (Study 8.6) and Groundwater Study Objective 6 that pertains to the Fish and Aquatics Instream Flow Study (IFS) (Study 8.5).

Study 7.5 ISR Part D was filed on November 6, 2015 and summarized the study status, highlighted results, and achievements; listed and provided links to the Study 7.5 documents; described variances and Study Plan modifications; and listed steps needed to complete the study. The *2014-2015 Study Implementation Report* was also filed on November 6, 2015 and contained four appendices: (1) Appendix A: *Preliminary Water Table Contour Maps for Focus Areas FA-104 (Whiskers Slough), FA-115 (Slough 6A), FA-128 (Slough 8A), and FA-138 (Gold Creek)*; (2) Appendix B: *Preliminary MODFLOW Three Dimensional Groundwater Model for FA-128 (Slough 8A)*; (3) Appendix C: *Summary Review of Susitna River Hydrogeologic Studies Conducted in the 1980s with Relevance to Proposed Susitna-Watana Dam Project and other Non-Project Related Studies*; and (4) Appendix D: *December 5, 2014 Technical Team Meeting Notes and Presentation*.

This Technical Memorandum (TM) (a supplement to Study 7.5 *2014-2015 Study Implementation Report* (November 9, 2015) and filed with FERC as Attachment 3 to *Response of the Alaska Energy Authority to Comments on the Initial Study Report*) describes and presents a GIS derived

[1] The FERC-approved Revised Study Plan (RSP) Section 7.5 for the Groundwater Study as modified by FERC's Study Plan Determination (Study 7.5 SPD, April 1, 2013), the *Riparian Instream Flow, Groundwater, and Riparian Vegetation Studies FERC Determination Response Technical Memorandum* (Study 7.5, 8.6, and 11.6 TM, July 1, 2013), the *Selection of Focus Areas and Study Sites in the Middle and Lower Susitna River for Instream Flow and Joint Resource Studies – 2013 and 2014 TM* (Study 8.5 TM, March 1, 2013), and the *Adjustments to Middle River Focus Areas TM* (Study 8.5 TM, May 31, 2013) is collectively referred to as Study Plan Section 7.5.

map series that depicts groundwater influenced areas identified within the entire Middle River Segment of the Susitna River.

Objective 4 of Groundwater Study 7.5 focused on groundwater upwelling, specifically targeting the identification of groundwater influenced areas within the entire Middle River Segment of the Susitna River. Information resulting from this study component was to include: 1) Geographic Information System (GIS) map layer of upwelling and groundwater influenced areas; and 2) analysis of the identified upwelling/spring areas to determine if they are (a) main flow/stage dependent, (b) regional/upland groundwater dependent, or (c) of mixed influence.

One of the key groundwater related factors associated with aquatic habitats pertains to upwelling. Many studies have shown the proclivity of salmonid species to utilize areas of groundwater upwelling for spawning and egg incubation. Durst (2000) summarized some of the more recent studies on this, with a focus on Alaska rivers, and pointed out the obvious survival benefits of groundwater upwelling as providing warmer winter temperatures to prevent freezing of eggs and to promote embryogenesis, and also providing sustained or increased intergravel flows that transport needed dissolved oxygen to and metabolic wastes from the developing embryos. The importance of groundwater upwelling and determining GW/SW relationships was also noted during the 1980s studies of the Su-Hydro Project with emphasis placed on selected slough habitats (Slough 8A, Slough 9, and Slough 11)[2] where salmon had been observed spawning (R&M 1985; Beaver 1984). In addition, specific groundwater upwelling locations were mapped at a number of survey locations in the Middle and Lower River as part of the 1980s studies; Estes and Schmidt (1983, Appendix F) reported the location of approximately 90 upwelling sites in the Middle River.

The information in this TM will be coupled with Focus Area-specific groundwater information, and data from other resource studies (Fluvial Geomorphology Modeling Study 6.6; Ice Processes Study 7.6; Fish and Aquatics Instream Flow (IFS) Study 8.5; and Riparian IFS (RIFS) Study 8.6) to classify the identified groundwater areas based on dependencies on river, upland groundwater, or mixed river/groundwater. The categorization or differentiation of groundwater types will be completed and presented in the Updated Study Report (USR).

2. STUDY OBJECTIVES

Groundwater Study Plan objectives were established in RSP Section 7.5.1 (AEA 2012). Objective 4 is to work with other resource studies to map groundwater-influenced aquatic and floodplain habitat (e.g., upwelling areas, springs, groundwater-dependent wetlands) within the Middle River Segment of the Susitna River, including within selected Focus Areas. The study component relied on the following activities and work products from other resource studies:

- Aerial and global positioning system (GPS) mapping of winter open leads as completed by the Ice Processes Study (Study 7.6);

[2] Slough 8A is contained within Focus Area FA-128 (Slough 8A); Slough 11 is contained within FA-138 (Gold Creek). Slough 9 is outside of the defined Focus Areas.

- Aerial Thermal Infrared Imagery (TIR) as provided from a temperature mapping study as part of Water Quality Study (Study 5.5);
- Observational data concerning GW/SW interactions collected as part of the Habitat Suitability Criteria (HSC) studies associated with spawning and/or rearing fish conducted under the Fish and Aquatics Instream Flow Study (Study 8.5); and
- Historic mapping of upwelling locations documented in 1982 and 1984, as appropriate.

This component of the Groundwater Study provides the compilation, review, and interpretation of the different mapping work products and resulted in development of a GIS map layer depicting potential groundwater influenced areas within the Middle River Segment of the Susitna River.

3. BACKGROUND AND METHODS

The initial step of this analysis was comprised of gathering existing 2012-2014 resource study data that may be used for the mapping process to determine which were most applicable for defining groundwater sources in the Middle River Segment of the Susitna River. The second step identified and selected a set of metrics that were used for distinguishing groundwater sources for each of the data sets. These included both quantitative metrics such as temperature differentials and vertical hydraulic gradient (VHG) measurements, as well as qualitative metrics such as visual detections of clear water zones during the open-water periods, or open-water leads during periods of ice cover. These metrics were used in the analysis of the data sets and served to delineate areas of groundwater influence that were incorporated into GIS map layers. The different sources of information utilized in this analysis are described below.

3.1. Ice Processes Study - Thermal Open Leads

The *Susitna River Ice Processes Study Report* (HDR 2013) documents the location of open-water leads in the ice cover in late winter and during ice breakup. Open leads from Cook Inlet to the Oshetna River (Project River Mile [PRM] 235.1) were mapped aerially and documented using GPS-enabled cameras in March 2012, before temperatures rose above freezing, and in April 2012 during ice breakup. Leads were classified by location (main channel, side channel, slough, or bank toe), type (thermal or velocity, where identifiable), disposition (continuous or discontinuous) and spatial extent (linear or ice hole). In the case of linear open leads, the upstream and downstream limits of each lead were located in the field using a handheld GPS unit, and the width of each lead was estimated visually as a percentage of river width. Leads classified as thermal in origin were generally shallow, located in marginal habitat areas and did not appear from the air to have a strong current (HDR 2013).

For the groundwater analysis, only thermal open leads in the Middle River Segment were used. This resulted in specific survey dates of March 21-22, 2012 for open leads located below Devils Canyon and April 4, 2012 for leads above Devils Canyon. Linear open lead GIS lines and points were re-delineated to fit within the habitat feature and then buffered by the average of the upstream and downstream width to create an open lead area (Figure 3-1). Ice holes remain as point features with no associated area.

Another component of the 2012 Ice Processes Study 7.6 report (HDR 2013) was a literature review of past studies documenting historic ice lead observations in the Susitna River. R&M mapped open leads on March 2, 1983, between Rabideux Creek (PRM 87.2) and Devils Canyon (approximately PRM 155.1) (Schoch 1984). R&M recorded the Historic River Mile[3] (RM) at the upstream end, length, widest width, location (main channel, side channel, or slough), type (thermal or velocity), and disposition (continuous or discontinuous). Leads classified as thermal indicated that the lead was kept open by groundwater seepage (Schoch 1984, Table 4.9). As before, only thermal open leads were used in the groundwater analysis. Using the recorded RM, channel type, and open lead length, linear open leads were digitized and then buffered one-half the widest width to create an open lead polygon (Figure 3-2).

The open lead surveys on March 12, 2013 and February 20-21 and April 2, 2014 were presented in the Ice Processes Study 7.6, 2014-2015 Study Implementation Report (SIR) (HDR 2015). The available GIS data at the time of this report were points and only classified by location and type (thermal or velocity). The thermal locations remain as point features and represent general presence or absence of open leads for the groundwater analysis.

3.2. Water Quality Study - Thermal Infrared Imagery

The *2012 Thermal Infrared Remote Sensing Pilot Test* (URS 2013) documents locations with large groundwater influence along the Susitna River from Talkeetna (PRM 100) to the proposed Watana Dam site (PRM 187.1) using the differential in temperature between warm groundwater and colder in-stream surface water. The survey was conducted on October 12-13, 2012 and October 17-18, 2012. Images were collected with a Forward Looking Infrared (FLIR) camera mounted on the underside of a helicopter at a flying height of 2,300 feet above ground level. To maximize thermal contrast, the Thermal Infrared (TIR) sensor was flown during early morning when solar loading was minimized. Susitna River temperature recorders were used for calibrating and verifying the thermal accuracy of the TIR imagery (URS 2013). On October 23, 24, 2013 and October 31, 2013, all ten Focus Areas and nine aquatic areas of interest in the Middle River Segment were resurveyed at a higher resolution than was collected in 2012 (1.6 foot image resolution versus 2.3-foot resolution). For the groundwater analysis, the 2012 and 2013 TIR study GIS file depicting increased groundwater activity was used (Figure 3-3). This layer was developed by qualitatively inspecting the thermal images for groundwater presence or absence based on water temperatures.

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[3] The Project River Mile (PRM) system for the Susitna River was developed to provide a consistent and accurate method of referencing features along the Susitna River. During the 1980s, researchers often referenced features by river mile without identifying the source map or reference system. If a feature is described by river mile or historic river mile (RM), then the exact location of that feature has not been verified. The use of PRMs provides a common reference system and ensures that the location of the feature can be verified. The PRM was constructed by digitizing the wetted width centerline of the main channel from 2011 Matanuska-Susitna Borough digital orthophotos. Project River Mile 0.0 was established as mean low water of the Susitna River confluence at Cook Inlet. A centerline corresponding to the channel thalweg was digitized upstream to the river source at Susitna Glacier using data collected as part of the 2012 flow routing transect measurements. The resultant line is an ArcGIS route feature class in which linear referencing tools may be applied. The use of RM will continue when citing a 1980s study or where the location of the feature has not been verified. Features identified by PRM are associated with an ArcGIS data layer and process, and signifies that the location has been verified and reproduced.

3.3. Instream Flow Study - Vertical Hydraulic Gradient

The IFS Study 8.5 and its component study efforts presented methods (Study 8.5 SIR, Appendix D: *Habitat Suitability Criteria Development* [R2 2015]) that provide quantitative indices of existing aquatic habitats that enable a determination of Project effects. As part of this effort, site-specific HSC were developed for various fish species and life stages for biologically relevant time periods in an effort to predict fish habitat use. These criteria included field observations of physical phenomena during summer and winter sampling events in 2013 and 2014 that included data collection of aquatic habitat depth, velocity, substrate, water quality, groundwater influence, and turbidity (R2 2015). Measurements identifying positive or negative intergravel flow, using a mini-piezometer for detecting the presence of groundwater upwelling or downwelling (VHG), were recorded. A detailed description of the 2013 VHG sampling methods is presented in Study 8.5 ISR Part A, Section 4.5.1.4 (R2 2014).

For this groundwater analysis, positive VHG measurements were selected from the HSC database at utilization/fish observation locations and then buffered 5 feet to provide an estimate of upwelling area. Vertical hydraulic gradient measurements collected along the sampling site were delineated in the GIS using the survey site downstream and upstream limits GPS locations and subsequently buffered the average survey transect width to produce an upwelling polygon (Figure 3-4).

3.4. Historic Spawning Surveys and Upwelling

Historic studies conducted as part of the 1980s Su-Hydro investigations specifically targeted the evaluation of SW/GW interactions and defining areas of groundwater upwelling. As noted in R2's (2013) review of the 1980s data, the importance of groundwater to fish and fish habitat in the Susitna River was first identified during studies when spawning salmon were observed to be associated with areas of groundwater upwelling. Trihey (1982) evaluated 13 of those areas and found that intergravel temperatures at those locations were higher and more stable than surface temperatures. Differences in intergravel dissolved oxygen concentrations were found between areas of groundwater upwelling and adjoining areas of surface flow, with concentrations generally lower in the upwelling areas.

Vining et al. (1985) suggested that upwelling was the single most important feature in maintaining the integrity of incubation in slough habitats of the Susitna River as well as localized areas in side channel habitats. The importance of groundwater on fish habitat was noted as being especially important during the winter time owing to its warming effects and benefits associated with temperature constancy and egg development and survival. Vining et al. (1985) found that salmon embryos located in macrohabitats that were most directly affected by Susitna River main channel stage fluctuations and that lacked groundwater upwelling developed more slowly and were more susceptible to high embryo mortality than areas with groundwater influence (Vining et al. 1985). Freezing and desiccation were the two primary sources of embryo mortality associated with the non-groundwater influenced areas. In addition to the importance to incubating salmon eggs, groundwater inflows to sloughs were also considered important as overwintering habitat (Dugan et al. 1984) that provided warmer water temperatures resulting in areas that were ice-free. Seagren and Wilkey (1985) provided a summary of water temperature and substrate data from salmon spawning and groundwater upwelling sites that had been collected in 1984 and 1985 in the Middle Susitna River. Specific groundwater upwelling locations were mapped at a number of survey locations in the Middle and Lower River as part of the 1980s studies; Estes and Schmidt (1983, Appendix F) reported the location of approximately 90 upwelling sites in the Middle River. For the groundwater analysis, the 1980s data were reviewed, with some selected for cross-comparison in a GIS map environment with more contemporary information. Specifically, upwelling and/or bank seepage locations mapped in Estes and Schmidt (1983, Appendix F) and Seagren and Wilkey (1985) were entered into the GIS as point locations and buffered 5 feet to create a general area of groundwater activity (Figure 3-5).

3.5. Data Analysis and Map Generation

To spatially summarize and map areas of potential groundwater influence, the following polygon features described in the methods section above were integrated using GIS merging software tools:

- Ice Processes Study: 2012-2013 Thermal Open Lead Aerial Observation Surveys (HDR 2013)
- Ice Processes Study: 1983 Thermal Open Lead Mapping from Literature Review (HDR 2013)
- Water Quality Study: 2012-2013 Thermal Infrared Imagery Aerial Surveys (URS 2013)
- Instream Flow Study: 2013-2014 HSC Vertical Hydraulic Gradient Ground Surveys (R2 2015)
- Instream Flow Study: 1982 and 1984 Upwelling and Bank Seepage Mapping from Fish Spawner Ground Surveys (Estes and Schmidt 1983, Appendix F)

Overlapping survey data were removed by aggregating features with groundwater activity present to provide a single polygon representation at all such locations. Figure 3-6 provides an example of this data processing step in slough and main channel habitats where delineations of groundwater influence based on the different source documents and field data were simplified. The next GIS processing step was a spatial overlay of Project River Mile and geomorphic reach GIS layers to obtain a variety of summary statistics (Table 3-1), longitudinal profiles (Figure 3-7 and Figure 3-8), and maps (Appendix A) of the Middle River Segment.

4. RESULTS

The results of this analysis, i.e., broad-scale mapping of potential groundwater influenced areas in the Middle River Segment of the Susitna River, are summarized by geomorphic reach in Table 3-1 and displayed in a 36-page, 11”x17”, 1:10,000 scale mapbook presented as Appendix A to this TM. The majority of groundwater areas are found in geomorphic reach MR-6 (PRM 148.4-122.7) and MR-7 (PRM 122.7-107.8), approximately 70 percent and 20 percent respectively (Table 3-1). The areas are primarily found in off-channel and tributary habitats (Appendix A, Map 16-34).

The longitudinal profile of the Middle River Segment in Figure 3-7 shows that the distribution of potential groundwater areas are cumulatively increasing between PRM 100 and PRM 128 at a constant slope. After PRM 128 near the downstream end of FA-128 (Slough 8A), the increase in area is more rapid until it plateaus near PRM 146 just upstream of FA-144 (Slough 21). Only about 7 percent of the mapped Middle River Segment groundwater influenced areas are found between PRM 146 and the proposed dam site (PRM 187.1). Figure 3-8 displays peaks where groundwater areas are more prolific than locations immediately upstream or downstream. Such locations include PRM 106 (FA-104 [Whiskers Creek]), PRM 113 (Slough 6), PRM 118 (Slough 8 and Lane Creek), PRM 126 (Moose Slough, Slough 8B, Slough 8C), PRM 130 (Slough 8A), PRM 135 (Fourth of July Creek and adjacent side channel habitat), PRM 140 (FA-128 [Slough 11]), and PRM 145 (FA-144 [Slough 21]). This again highlights the relationship between groundwater influenced areas and slough habitats.

5. DISCUSSION AND CONCLUSIONS

This analysis provides an example of how quantitative and qualitative aerial and ground field efforts from multiple resource studies can be used for distinguishing potential groundwater sources. The resultant set of GIS derived maps and spatially enabled data (Appendix A) are useful products for identifying areas that are likely influenced by groundwater and provide a tool for validating multi-disciplinary Focus Area model results and subsequent Middle River Segment expansion.

Current Groundwater Study (Section 7.5) modeling efforts have looked at the response in groundwater elevation during changes in the Susitna River mainstem stage during the winter melt out period (June and July). Both correlation and Root Mean Square Error (RMSE) (a proxy for the absolute difference in elevation profiles) have been analyzed. Most groundwater elevations in FA-128 (Slough 8A) wells that are situated in a side slough and on a vegetated island are highly correlated and most have low RMSE. By contrast, in FA-115 (Slough 6A) correlation is weaker and RMSE is greater. Correspondence in stage and groundwater elevation changes completely breaks down in wells furthest upland and away from the main channel. This suggests that it may be possible to develop a categorization for influence on groundwater by the Susitna River mainstem. The categorization or differentiation of groundwater types into three categories – riverine dominated; transitional; and upland dominated will be completed for and reported in the Updated Study Report (USR). These categories are consistent with those described in SIR Study 7.5, Section 4.4.

Another recent groundwater modeling effort provided potentially valid expansion/extrapolation areas for FA-128 (Slough 8A) groundwater processes where observed temperatures greater than 0.85° Celsius were indicative of nearby upwelling model grid cells. Thermal Infrared imagery temperatures greater than 0.85° Celsius (274° Kelvin) could be selected from the geo-rectified thermal images in valid extrapolation areas to quantify potential groundwater activity. Groundwater modeling in Focus Areas beyond FA-128 (Slough 8A) will be completed for the USR enabling this upscaling of Focus Area groundwater processes.

Although the upwelling broad-scale mapping effort has been completed, there are multiple activities remaining for the USR that need to be completed before final groundwater influenced areas (categorized by dependencies on river, upland groundwater, or mixed river/groundwater) within the entire Middle River Segment of the river can be developed. These include the following:

- Selection and agreement on all upwelling indicator variables and spatial representations;
- Finalization of Focus Area groundwater analysis to allow Middle River Segment upscaling; and
- Finalization of Focus Area groundwater models for categorization of groundwater types.

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7. TABLES

Table 3-1. Summary of potential groundwater influenced areas by geomorphic reach in the Susitna Middle River Segment.

Geomorphic Reach	Acres	Reach Breaks (PRM / *RM*)[1]		Slope (ft/mi)[1]	Lateral Constraints[1]
		Upstream	Downstream		
MR-1	0.4	187.1 / *184.3*	184.6 / *181.9*	9.2	Tertiary-Cretaceous Gneiss
MR-2	6.8	184.6 / *181.9*	169.6 / *166.4*	10.8	Cretaceous Kahiltna Flysch Tertiary-Cretaceous Gneiss
MR-3	0.7	169.6 / *166.4*	166.1 / *163.0*	12.3	Paleocene Granites
MR-4	3.3	166.1 / *163.0*	153.9 / *150.3*	30.6	Paleocene Granites
MR-5	2.6	153.9 / *150.3*	148.4 / *144.9*	12.3	Cretaceous Kahiltna Flysch
MR-6	492.9	148.4 / *144.9*	122.7 / *118.9*	10.7	Cretaceous Kahiltna Flysch with undifferentiated Upper Pleistocene moraines, kames, lacustrine deposits
MR-7	151.7	122.7 / *118.9*	107.8 / *104.1*	8.3	Cretaceous Kahiltna Flysch with undifferentiated Upper Pleistocene moraines, kames, lacustrine deposits
MR-8	55.0	107.8 / *104.1*	102.4 / *98.6*	8.8	Upper Pleistocene moraines, outwash and Holocene Alluvial Terrace deposits

Notes:
[1]Information from Table 5.2-1 in Study 6.5 SIR, Attachment 1: *Geomorphic Reach Delineation and Characterization, Upper, Middle and Lower Susitna River Segments – 2015 Update Technical Memorandum*

8. FIGURES

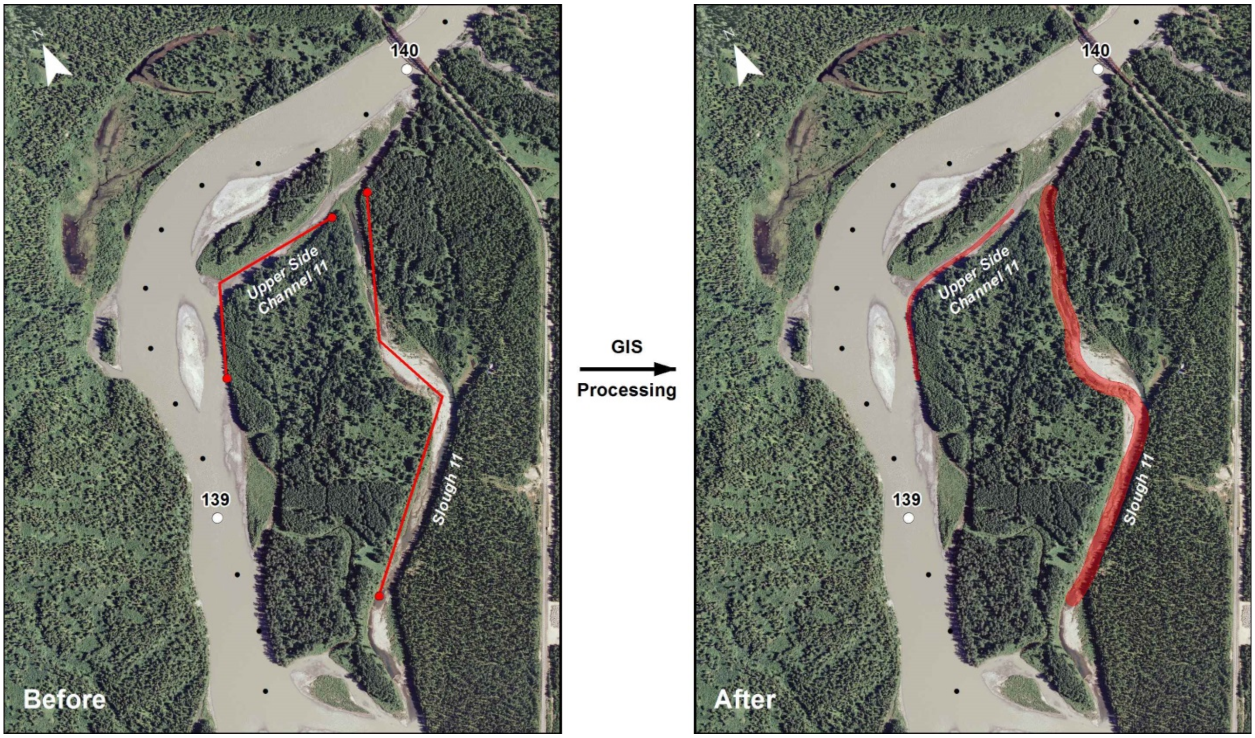

Figure 3-1. Example GIS process of converting 2012 Ice Study thermal open lead lines and points to buffered areas in Upper Side Channel 11 and Slough 11, FA- 138 (Gold Creek).

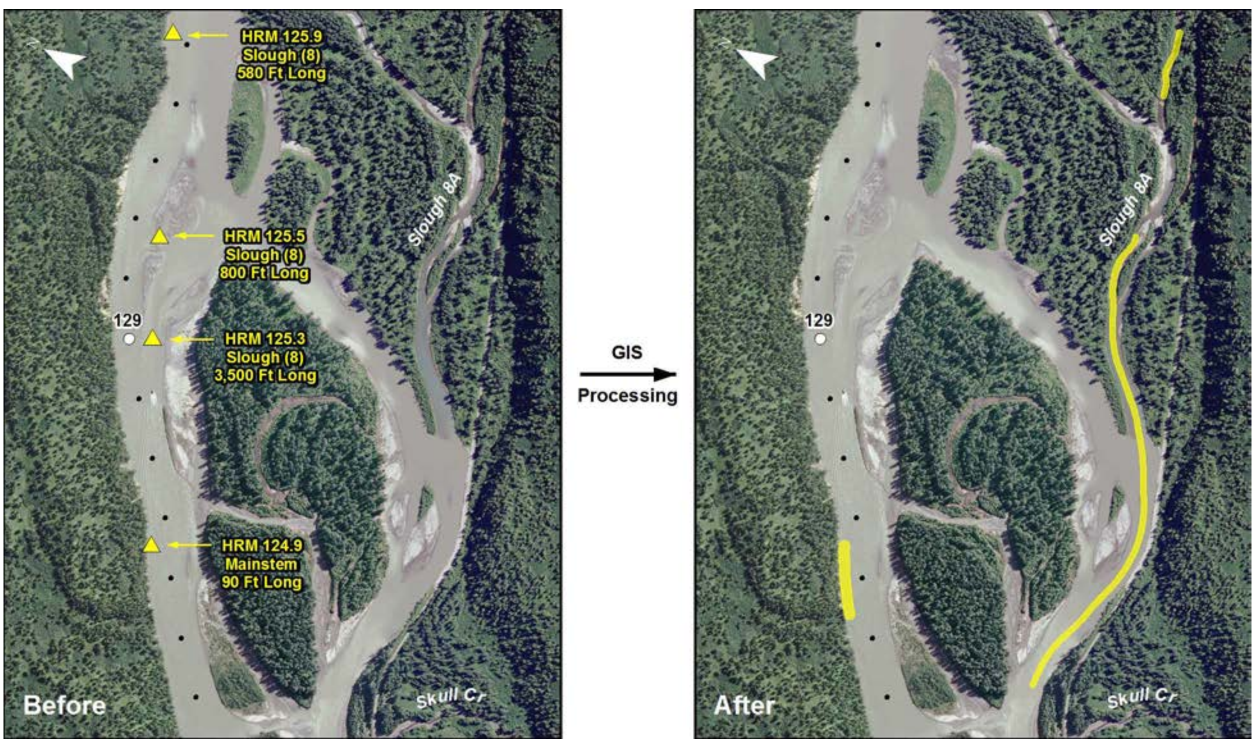

Figure 3-2. Example GIS process of converting 1983 thermal open ice lead observation points to buffered areas in Slough 8A and main channel habitat at PRM 128.6, FA-128 (Slough 8A).

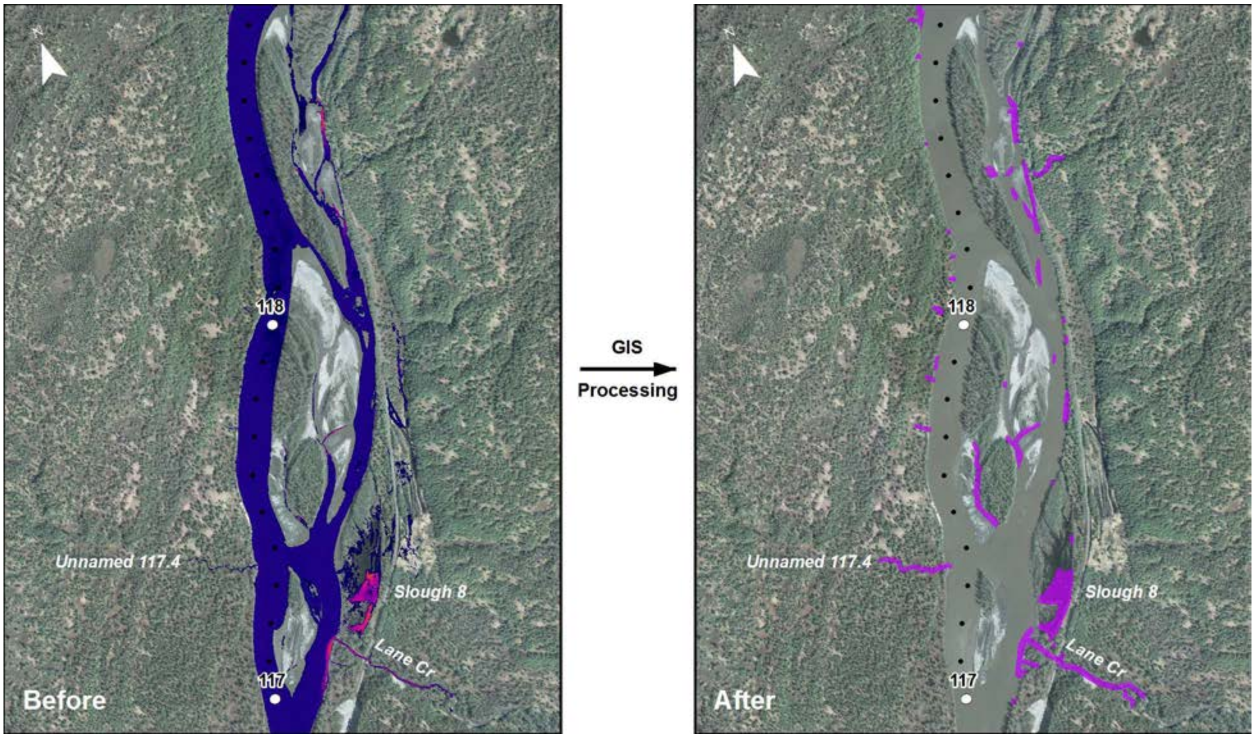

Figure 3-3. Example GIS process of converting 2012 thermal infrared imagery to increased groundwater activity areas in Unnamed Tributary 117.4, Slough 8, Lane Creek, and main channel habitat between PRM 117 and 118.8.

Figure 3-4. Example GIS process of converting 2013-2014 Instream Flow Study HSC vertical hydraulic gradient sample locations (points) and sample sites (lines) to buffered areas in Side Channel 21, FA-144 (Slough 21).

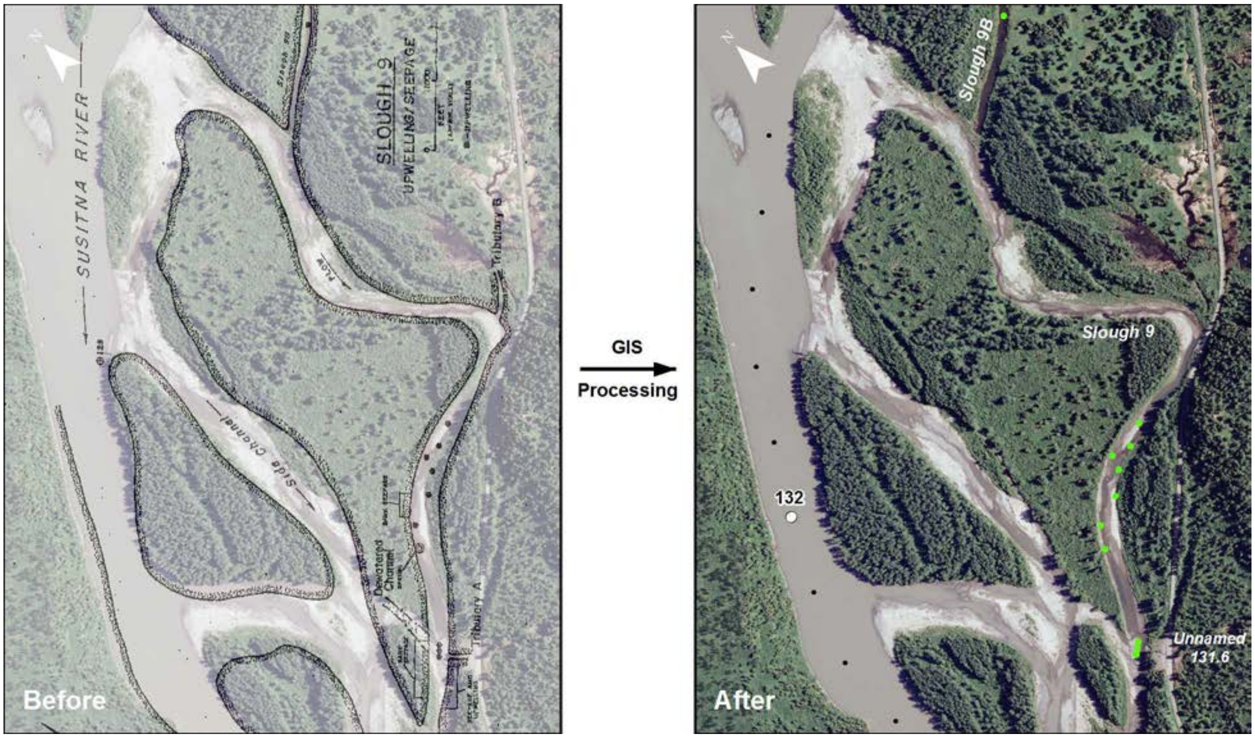

Figure 3-5. Example GIS process of converting 1982 open-water upwelling locations to buffered areas in Slough 9 and Slough 9B, PRM 131.6 to PRM 132.6.

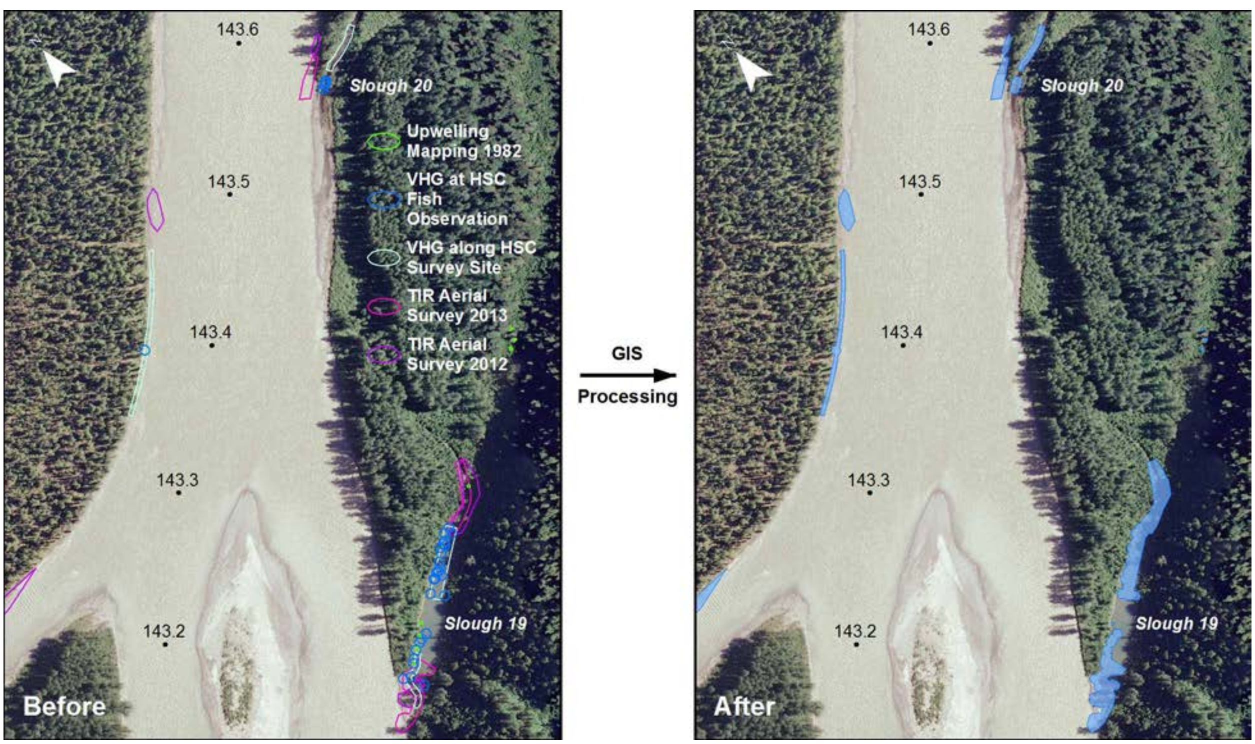

Figure 3-6. Example GIS process of aggregating overlapping survey data to a single groundwater activity polygon in Slough 19, Slough 20, and mainstem habitat from PRM 143.2 to PRM 143.5 at the upstream end of FA-141 (Indian River).

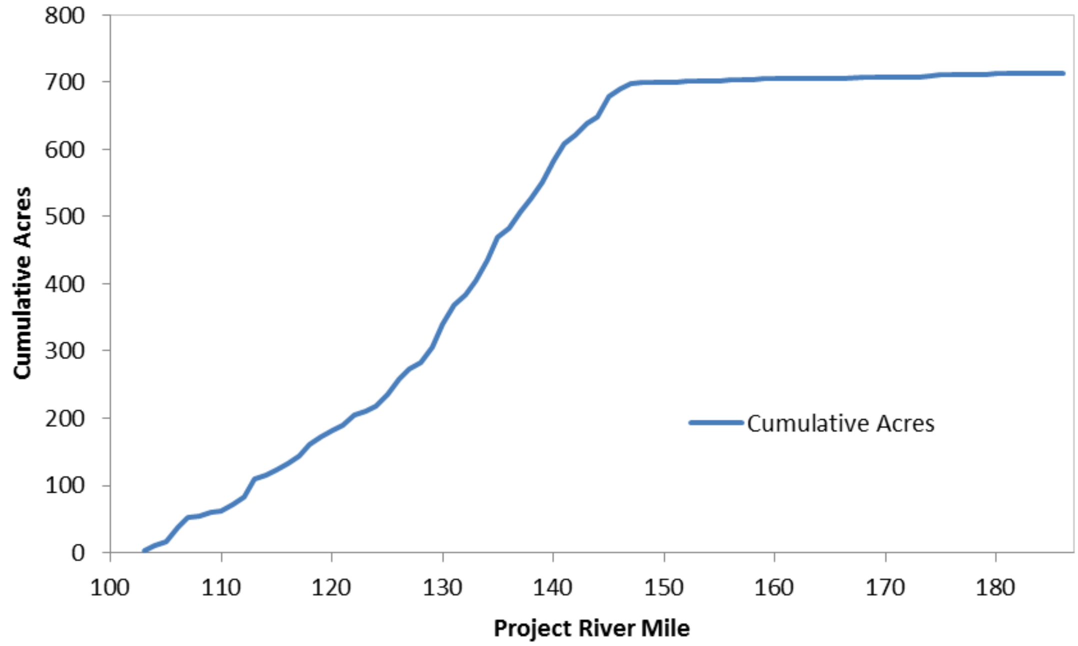

Figure 3-7. Longitudinal distribution of potential groundwater influenced areas in the Middle River Segment of the Susitna River. See Appendix A for GIS delineations of specific groundwater areas.

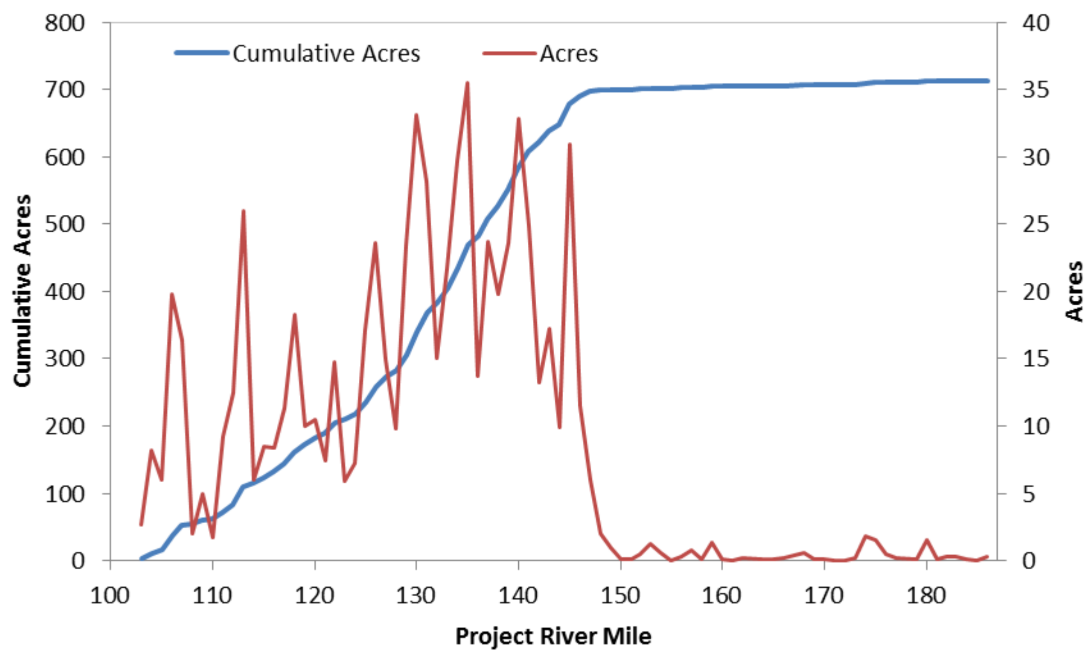

Figure 3-8. Cumulative and Project River Mile based longitudinal distribution of potential groundwater influenced areas in the Middle River Segment of the Susitna River. See Appendix A for GIS delineations of specific groundwater areas.

APPENDIX A: LOCATIONS OF POTENTIAL GROUNDWATER INFLUENCED AREAS WITHIN THE MIDDLE SUSITNA RIVER