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Summary Report

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Fluvial Transport of Human Remains: Forensic Application of a HEC-RAS Model for Predicting Search Parameters for Human Remains Recovered from the Sacramento River, CA

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Project Overview

Rivers, streams, lakes, bays, and oceans are all responsible for the long distance transport of human remains away from their original point of entry into the water (e.g., drownings, suicides, body dumps, etc.). For law enforcement and search and rescue teams, identifying search parameters for deceased persons in bodies of water is challenging and often requires significant expenditure of time, money, and resources (Modell 2006). Identifying search parameters becomes increasingly challenging over longer postmortem intervals such as multiple days or weeks (Evans 2014). At present, the fluvial transport of human remains is one of the least understood areas of taphonomic research in the forensic literature.

Currently, there are no established methods within the medicolegal community or in the forensic literature for predicting transport rates or search parameters for river victims (Evans 2014; Lunetta et al. 2014; Modell 2006). This can be attributed to several factors. First, because each fluvial environment is unique, a tailored model needs to be generated for each fluvial system that takes into account seasonal fluctuations in flow rates, river dimensions, river curvature, and the presence of snags and other obstructions. Second, little experimental research has been conducted using human remains models (e.g., rescue mannequins) in fluvial systems, in part due to complex logistics surrounding this type of research (Dilen 1984; Evans 2014). Retrospective surveys of river victims often lack the necessary detail to develop a useful predictive model (Bassett and Manheim 2002; Modell 2006). Third, law enforcement personnel and search and rescue teams are trained using a set of protocols that were developed through past experience in body recovery efforts from riverine environments and not using predictive models using flow rate data (Modell 2006).

The Sacramento River is California's largest river, flowing over 350 miles north to south from Mount Shasta to the Sacramento-San Joaquin Delta, and traversing eight northern California counties (Mount 1995). Flow rates are regulated by Shasta Dam at the river's source, and are influenced by the numerous tributaries that feed into the river as well as by the physical characteristics of the river. The highest flow rates occur during winter storm events and the lowest during the late fall, after the irrigation season has ended. Each year, the river claims many lives due to drownings, boating accidents, and suicides. In addition, it is a common body dump location for homicide victims. Given the fluvial dynamics of the river, bodies of river victims are commonly transported away from their original point of origin. No standardized search protocols exist for riverine systems, which presents challenges for search and rescue and law enforcement teams tasked with locating river victims.

The current project was developed to create fluvial transport models to predict where to search for human bodies within the Sacramento River (see Appendix A: Map of the Project Area). The research design included data collection on historical cases of river victims from law enforcement agencies located along the Sacramento River. Data collection included dates, times, and locations of entry and exit from the river where possible. Next, both "sinker" and "floater" water rescue mannequins were used to simulate dead bodies in the submerged and floating stages, respectively. GPS and salmon tracker devices were used to evaluate transport rates of the floater mannequins in multiple locations along the southern half of the river, and under low (<6000 cfs), medium (6000-9000 cfs), and high (>9000 cfs) flow conditions (Appendix B). We adapted an existing hydraulic model, known as the Hydrologic Engineering Center's River Analysis System (HEC-RAS) model to predict transport rates under different flow rate conditions. Floater mannequin data were used to calibrate the model. Sinker mannequin trials were also conducted under low to medium flow rate conditions during the submerged phases of the research, which allowed us to estimate transport during the lag time between deposition in the river and fluvial transport on the surface. The model data from HEC-RAS was used to develop the web-based *Sac River Search* app, which will allow law enforcement and search and rescue teams to predict a search area for river victims using Sacramento River flow rate parameters, entry location, and time since entry into the river. This research has been presented to law enforcement and search and rescue teams who plan to use the app as part of their river rescue and recovery teams.

Historical Data Collection

Historical data was collected from six counties through which the Sacramento River passes, including Butte, Glenn, Colusa, Sutter, Sacramento, and Yolo Counties. Data collection forms included general case information, victim demographics (sex, age, ancestry, stature, and weight), date and location of entry into the river, date and location of recovery from the river, transport distance, cause and manner of death, stage of decomposition, completeness of the body, and whether the remains were caught on a snag within the river. All case records were screened to identify appropriate Sacramento River victims, although completeness of information varied substantially. The historical cases dated between 1970 and 2022. In total, data were collected on 66 cases from local sheriff-coroner's offices located within the counties in the study area. Of these, 14 were potentially usable for evaluating, as they have the date of entry to the river and date of recovery (thus providing the transport distance during the time period the remains were in the river) and the location of entry and recovery. In addition to the case data, GIC staff obtained historical centerlines of the river, as it is a dynamic system and the location of the channel can change following high flow events. This causes the actual distance between two points to change, according to whether the centerline increases or decreases in length and using the historical centerlines provides greater accuracy in the transport distance. The data were converted to GPS coordinates based on the nearest landmark to the body recovery location. In total, 52 river victims were male, 10 were female, and four unidentified remains cases were of indeterminate sex. Nine cases represented suicides, two represented homicides, one was a natural death, 29 represented accidents (most are drownings), and the remaining 11 cases are undetermined deaths. Most cases in the data set are from river victims that were recovered less than 3 days from the time reported by a witness (with 3 outlier cases removed with >100 days in the river). The data from the historic cases, along with the rescue mannequin data from the field trials, was used to test the HEC-RAS model. An analysis of 53 Sacramento River historic cases (from all counties through which the river travels) found a moderate correlation between the number of days a body was in the river and the river miles traveled (Pearsons's correlation = .583, $p<.001$; $r^2 = .34$; excluding outliers >80 days in river and >20 miles traveled). This suggests that flow rates play an important role in understanding the unexplained variation.

Field Trials

The main goal of the field trials was to determine how bodies transport in a fluvial environment and then replicate it in a manner that would allow us to collect data for future modeling. To best simulate body transportation, it was determined using rescue mannequins that float would be the best option. The Ruth Lee Man Overboard model was chosen for simulation (Appendix C). The mannequin is 5' 11" in height and weighs 88 pounds when dry. They were configured to float in the 45-degree position that best mimics what happens in drownings.

Field trials were conducted along the Sacramento River from River Mile 199, near Hamilton City California, to River Mile 80, near Verona California. The trials were designed to sample as much of the river stretch as possible and record data that would allow for modeling and location predictions. With this in mind, the study area was further divided into 20 sub-reaches based on access points and estimated travel distances (Appendix D). Each sub-reach had three planned mannequin releases based on predefined flow intervals. These intervals were calculated using historic hourly flow records spanning from Jan. 1, 1984 - Dec 1, 2017 (approximately 33 years of hourly data). These flow rates were defined as Low – any flow below 6,000 cubic feet per second (cfs), Medium – any flow between 6,001 and 9,000 cfs, and High – any flow above 9,000 cfs.

Mannequins were outfitted with one radio frequency emitter to allow for radio frequency tracking and recovery in the case that visual contact was lost (Appendices E & F). Additionally, for each release location and flow regime, one of the three mannequins was also outfitted with a GPS tracking device (Appendix G). This device allowed for detailed transport data tracking as it took a reading every two minutes. Mannequins were released at each sub-reach start, with one at river-right, one at river-middle, and one at river-left (Appendix H). A GPS location recording along with the time was recorded for each mannequin. Trial rules allowed for each mannequin to have 1 restart (which would create a new recording) per day if it became stranded after the first three hours of a release (e.g., caught on a snag). Each mannequin was then followed by boat during the trial. This was provided to prevent unnecessary public panic or disruption of the trial by unnatural events. The trial could be stopped at any time for staff safety or to prevent the loss of the mannequin. Critical information recorded on the field data sheet included start and end latitude/longitude, start and end times, stranded/snagged times and locations, and any potential restarts needed as described above (Appendix I). These sheets were used in testing and verifying transport model predictions.

GPS data logger recordings were attempted for all release locations and flow regimes in the case of technical failures (functional loss of 2 of the 3 GPS data loggers) or natural conditions that did not allow tracking (receiver was underwater due to mannequin float position changes). In total 5 low flow releases, 2 medium flow releases, and 5 high flow releases were missing the detailed data logger recordings (Appendix J). Time and budget did not allow for these trials to be attempted again. However, the total number of successful trials was greater than the number originally proposed.

To understand the process from a drowning event to the point at which transport begins, ancillary data was collected using "sinker" mannequins (Appendix C). Four locations were identified in the project area that allowed for safe access and data recording on gravel bars. Submerged transport was observed, recording flow velocity, transport time, transport distance, and substrate. These data were not used in the later modeling but only for a better understanding of what would be required to start the fluvial transport of a recent drowning. Test transects were used where the sinker mannequin was released and transport was observed and measured. This could only be done under low and medium flow conditions due to safety issues, and required that personnel walk up to waist deep in the river. We collected data on transport distance, and flow and depth were recorded using a SonTek FlowTracker (Appendix K & L). We documented the substrate (sandy, gravel, etc.), took photo examples, and noted other general observations (Appendix M & N). Preliminary observations, which were based solely on easy-to-access gravel bars, suggest minimal transport for submerged mannequins, especially under low flow conditions. Transport occurred more readily in shallow water than deeper water, and mannequins moved more under medium-sized gravel substrates than sandier substrates and larger cobble substrates. Also, river turbulence seemed to encourage transport. For cobble substrates, velocities over 2.7 ft/sec were sufficient to move the sinker mannequin at the bottom. For sand/gravel substrates, velocities over 2.0 ft/sec were sufficient to move the sinker mannequin.

Neutrally buoyant transport was discussed as a potential field trial and equipment was successfully designed under controlled conditions. After further discussions, it was deemed to not be a viable option for trials as river conditions are too variable to allow for repeatable tests. Temperature stratification and unpredictable subsurface currents made the potential loss of the only neutral buoyant mannequin too risky. However, an experimental design was developed in conjunction with the College of Engineering at Chico State to develop a prototype of a neutrally buoyant mannequin for future research.

Hydraulic Modeling

The hydraulic simulations were performed using the Army Corps of Engineers Hydraulic Engineering Center River Analysis System (HEC-RAS). The base model was obtained from the California Department of Water Resources (DWR) Central Valley Floodplain Evaluation Delineation (CVFED) Program, which was designed to simulate flood conditions along the Sacramento River. This model was constructed using a beta version of HEC-RAS that is not fully compatible with standard releases of HEC-RAS. As such, the model produced errors when simulating our conditions and needed modification to produce meaningful simulations. This included: 1) removing all storage areas (we are not simulating flood conditions where there is significant storage within the floodplain outside of the main channel); 2) the model was trimmed to just our study area rather than the much longer length of the Sacramento River; and 3) boundary conditions were modified to conform to our simulated test cases. Without these modifications, the model would not run correctly.

These models were compared to actual stream gauge data from the California Data Exchange Center (CDEC) to check for reasonable accuracy of simulated flow and stage (depth). A threshold of 20% error was used to determine if the models provided accurate simulation of the Sacramento River flows for the test cases. For the low flows, 1 of the models had flow rate errors larger than 20% while 6 of the high flows had errors larger than 20%. None of the medium flows exceeded 20% error. The results are summarized in the following table (see Table 1).

Table 1. All floater and sinker tests were performed from November 2017 to March 2021. Unless otherwise denoted, a test was performed using a floater mannequin, and a flow model was created for each test. Flow models highlighted in red had errors that were too high when compared to CDEC flows. Flow models displayed with gold text were used in the transport model calibration. Flow models highlighted in yellow were used in the predictive simulation. For float tests that are highlighted in gray, the dummy was not able to move in the water. Data was not collected for cells that are blacked out.

Release Locations	Gauge	Release Date Low Flow (Daily cfs)	Release Date Medium Flow (Daily cfs)	Release Date High Flow (Daily cfs)
Irvin Finch	Hamilton City (HMC)	11/15/2018 (3,820 cfs) **GPS**	9/27/2018 (6,665 cfs) **GPS**	7/26/2018 (9,564 cfs)
Beer Can Beach	Hamilton City (HMC)	11/15/2017 (5,646 cfs)	9/25/2018 (6,627 cfs) **GPS**	7/25/2018 (9,598 cfs)
Washout	Hamilton City (HMC)	11/13/2018 (3,765 cfs) **GPS**	9/24/2018 (6,714 cfs) **GPS**	7/24/2018 (9,637 cfs)
Ord Bend	Ord Bend (ORD)	11/19/2018 (4,829 cfs)	9/20/2018 (7,017 cfs) **GPS**	11/17/2017 (10,872 cfs)
RM 181	Ord Bend (ORD)	11/20/2018 (4,829 cfs)	10/2/2018 (6,550 cfs) **GPS**	1/23/2019 (20,390 cfs) **GPS**
RM 175	Ord Bend (ORD)	2/18/2020 (5,191 cfs) **GPS**	10/9/2018 (6,840 cfs) **GPS**	1/11/2019 (18,346 cfs) **GPS**
Butte City	Butte City (BTC)	11/5/2018 (4,746 cfs) **GPS**	9/18/2018 (7,815 cfs) **GPS**	1/22/2019 (36,000 cfs) **GPS**
Princeton	Butte City (BTC)	11/6/2018 (4,585 cfs)	9/14/2018 (7,784 cfs) **GPS**	2/4/2019 (47,120 cfs)
RM 155	Butte City (BTC)	12/10/2018 (4,592 cfs) **GPS**	10/1/2018 (6,923 cfs) **GPS**	1/29/2019 (10,310 cfs) **GPS**
RM 149	Butte City (BTC)	12/6/2018 (4,968 cfs) **GPS**	10/11/2018 (7,125 cfs) **GPS**	1/30/2019 (9,874 cfs) **GPS**
Colusa	Colusa Bridge (COL)	11/8/2018 (3,894 cfs)	9/11/2018 (7,722 cfs)	12/19/2018 (12,139 cfs) **GPS**
Wards Landing	Colusa Bridge (COL)	12/11/2018 (4,517 cfs) **GPS**	9/13/2018 (7,630 cfs) **GPS**	1/14/2019 (10,424 cfs) **GPS**
Meridian Bridge	Colusa Bridge (COL)	2/14/2018 (5,585 cfs) **GPS**	9/6/2018 (7,961 cfs) **GPS**	2/5/2019 (42,380 cfs) **GPS**
RM 129	Colusa Bridge (COL)	12/13/2018 (4,385 cfs) **GPS**	10/15/2018 (6,288 cfs) **GPS**	2/7/2019 (25,119 cfs) **GPS**
Grimes	Colusa Bridge (COL)	2/15/2018 (5,463 cfs) **GPS**	9/7/2018 (7,817 cfs) **GPS**	2/11/2019 (15,594 cfs) **GPS**
Tisdale	Colusa Bridge (COL)	12/14/2018 (4,389 cfs) **GPS**	2/7/2018 (6,497 cfs) **GPS**	2/15/2019 (47,629 cfs) **GPS**
RM 110.5	Colusa Bridge (COL)	2/21/2020 (4,902) **GPS**	10/8/2018 (7,170 cfs) **GPS**	2/20/2019 (23,976 cfs) **GPS**
RM 100	Colusa Bridge (COL)	2/12/2020 (5,919 cfs) **GPS**		1/29/2020 (13,372 cfs) **GPS**
Knights Landing	Colusa Bridge (COL)	1/3/2019 (5,604 cfs) **GPS**	2/8/2018 (6,296 cfs) **GPS**	2/12/2019 (14,668 cfs) **GPS**
RM 84	Colusa Bridge (COL)	1/4/2019 (5,571 cfs) **GPS**	10/4/2018 (6,861 cfs) **GPS**	2/13/2019 (15,857 cfs) **GPS**
Beer Can Beach (Sinker)	Hamilton City (HMC)	2/9/2018 (5,095 cfs)		
Island below Scottys (Sinker)	Hamilton City (HMC)	3/29/2021 (4,774 cfs)	6/27/2018 (8,249 cfs)	
Golden State Island (Sinker)	Ord Bend (ORD)	3/25/2021 (4,991 cfs)	6/28/2018 (7,878 cfs)	
Ord Bend (Sinker)	Ord Bend (ORD)	3/25/2021 (4,991 cfs)	6/29/2018 (7,831 cfs)	

Challenges Working with the HEC-RAS Models

HEC-RAS is a widely used tool for floodplain delineation and analysis, and consequently, many major rivers in the United States have HEC-RAS models already developed. Therefore, using HEC-RAS as the basis of the hydraulic simulations makes the methods used in this study widely transferable. However, as part of this study, three challenges were identified for using HEC-RAS models developed for floodplain analysis and applying them to studies of fluvial transport of human remains.

1) Many large-scale HEC-RAS floodplain models are 1-dimensional models where flow velocity is only considered in the streamwise direction, but actual flow velocities are 3-dimensional. Currently, HEC-RAS has the capability of 2-dimensional flow modeling (streamwise and cross-stream direction), which would be helpful for simulating phenomena near the banks that affect transport (e.g., slower velocity near the banks vs. the centerline, eddies that develop around bends), but these models tend to be used for smaller-scale simulations as the data input requirements and computational demands are higher. Two-dimensional or three-dimensional models would be better able to simulate these processes, and, in theory, provide better predictions of transport.
2) Many numerical models exhibit instabilities when their model inputs are changed (as might be done during sensitivity analysis). The base version of the HEC-RAS model that was used in this study exhibited some instabilities that affected the simulated velocities, which in turn affected simulated transport. The base model was developed for simulating large flows related to flood events, whereas our study required simulations over a different range of input flow conditions (including low and medium flows), for which the

original model was not designed. This will likely be the case for other HEC-RAS models that are adapted from floodplain studies.

3) The area used in this study is primarily in a rural and agricultural setting. Because the base model was developed for floodplain delineation, agricultural diversions and return flows were not incorporated into the original model. Agricultural diversions in California are recorded in the Electronic Water Rights Information Management System (eWRIMS) database, however, reporting is aggregated on a monthly time scale. The tests with the floating mannequins to which the models where calibrated were typically on the order of a few hours of flow and transport time. The additional models used in this study simulated predictions of flow and transport over a time of a few days. Thus, there was not a good way to incorporate the effects of agricultural diversions and returns flows into the calibration and prediction models due to the differing timescales for the simulated transport events vs time over which diversion data are aggregated and recorded. However, agricultural diversions and return flows can affect the flow (both spatially and temporally) in the study area.

GPS Data Logger Results

A python script was created that utilizes the GPS data recorded during some of the floater tests. The script takes the starting position, starting time, and associated flow model for each float test (colored with gold text in Table 1) to calculate the mannequin location every two minutes to match the two-minute output timer on the GPS. An additional python script utilizes the float tests that did not have a GPS tracker. This script was made to test the consistency of the transport scheme.

Transport Modeling

HEC-RAS's built-in water quality module that simulates advective-dispersive transport is not compatible with the RAS controller that was used to automate each hydraulic simulation. As a workaround, we developed a python script to use the velocities calculated by HEC-RAS in a purely advective transport scheme. The GPS data were used to calibrate the transport model using UCODE_2014 (Poeter et al., 2014) by defining transport parameters over the reaches between the nearest river gages (Hamilton City – HMC; Ord Ferry – ORD; Butte City – BTC; and Colusa – COL) and the 3 flow conditions (low, medium, and high). After calibrating the model to the observed GPS transport data, the model was run in a predictive mode by starting a body at half-mile increments from River Mile 90 through River Mile 199 (essentially the downstream end of the model to the upstream beginning of the model) for flow rates spanning low flows (3765 cfs) to high flows (42,380 cfs), with its location recorded in 30-minute intervals. Using the uncertainty based on the calibration, UCODE_2014 was used to calculate 95% prediction intervals for each location that can be used to provide a search box upstream and downstream of the predicted location. This data set of 195,000 records was interpolated onto flow increments of every 100 cfs to build a look-up table to be used in the Sac River Search app.

Cross Validation Testing of Predictive of Accuracy

A cross validation analysis was performed to test the predictive accuracy of the look-up data table generated by the predictive transport model. This look-up data table is used in the Sac River Search app and consequently measures the predictive accuracy of the app and indicates how well the app might work in practice.

The cross validation used data from 206 float tests of mannequins that did not have continuous GPS data and therefore were not part of the calibration data set. This data set spanned all locations (HMC, ORD, BTC, and COL) and all flow conditions (low, medium, and high) except for high flow conditions at HMC. Based on 3 inputs, 1) flow, 2) starting location (river mile), and 3) transport time, the ending transport location (river mile) was extracted from the look-up table and compared to the actual ending transport location. These results were analyzed to determine the difference between the predicted location and the actual location to characterize the predictive accuracy of the look-up table used in the Sac River Search app. Table 2 summarizes the predictive accuracy based on what percentage of the predicted locations of the cross-validation data were within a designated +/- river miles of the actual location. For example, Table 2 shows that 51% of the actual locations are within +/- 0.5 river miles (RM) of the predicted locations and 73% are within +/- 1 river mile.

Table 2. Summary of the predictive accuracy of the look-up table based on 206 cross-validation data. Shading from red to green indicates the percentage of cases where the predicted location was within the designated number of river miles (RM) of the actual location.

RM +/-	
0.1	12%
0.2	25%
0.3	34%
0.4	44%
0.5	51%
0.6	57%
0.7	65%
0.8	68%
0.9	70%
1	73%
2	89%
3	96%
4	99%
6.7	100%

Additional analyses of the cross-validation tests were performed to characterize the fidelity of the predictive look-up table in terms of both location and flow conditions. These results are shown in Table 3 and Table 4

The results in Table 3 can be interpreted the same as Table 2 as the percentage of the predicted locations of the cross-validation data within a designated +/- river miles of the actual location. Table 3 indicates how the fidelity of the predicted location using the look-up table varies depending on location and flow condition.

Table 3. Summary of the predictive accuracy of the look-up table predicted location based on 206 cross-validation data. Shading from red to green indicates the percentage of cases where the predicted location was within the designated number of river miles (RM) of the actual location. Columns indicate location (Hamilton City = HMC; Ord Ferry = ORD; Butte City = BTC; and Colusa = COL) and flow condition (low=L; medium=M; and high=H). There were no cross-validation data for Hamilton City under high flow conditions.

RM +/-	HMC_M	HMC_L	ORD_H	ORD_M	ORD_L	BTC_H	BTC_M	BTC_L	COL_H	COL_M	COL_L
0.1	14%	13%	5%	0%	31%	13%	6%	20%	17%	11%	10%
0.2	29%	13%	21%	8%	46%	19%	12%	40%	25%	27%	27%
0.3	43%	38%	32%	8%	62%	31%	12%	53%	29%	41%	30%
0.4	57%	75%	37%	8%	85%	38%	24%	53%	33%	59%	33%
0.5	57%	88%	42%	15%	92%	38%	29%	73%	42%	59%	50%
0.6	64%	88%	47%	23%	100%	44%	29%	80%	42%	65%	60%
0.7	71%	100%	53%	38%	100%	56%	47%	80%	50%	70%	70%
0.8	71%	100%	53%	46%	100%	56%	47%	80%	54%	76%	77%
0.9	71%	100%	58%	46%	100%	63%	53%	80%	54%	78%	77%
1	71%	100%	63%	54%	100%	69%	53%	87%	54%	84%	77%
2	93%	100%	84%	85%	100%	94%	71%	100%	71%	95%	97%
3	93%	100%	95%	92%	100%	94%	100%	100%	88%	97%	100%
4	100%	100%	95%	100%	100%	94%	100%	100%	100%	100%	100%
6.7	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

In addition to the predicted location, the look-up table also provides estimates of the +/- 95% prediction intervals that can be used to set a search box upstream and downstream of the predicted location. The results in Table 4 in can be interpreted the same as Table 3 as the percentage of the actual locations of the cross-validation data within the predicted lower limit of the search box, the predicted upper limit of the search box, and within the predicted search box (i.e., within both the lower and upper limits).

Table 4. Summary of the predictive accuracy of the look-up table based on 206 cross-validation data. Shading from red to green indicates the percentage of cases where the actual transport is within the predicted lower limit, the predicted upper limit, and within the predicted search box. Columns indicate location (Hamilton City = HMC; Ord Ferry = ORD; Butte City = BTC; and Colusa = COL) and flow condition (low=L; medium=M; and high=H). There were no cross-validation data for Hamilton City under high flow conditions.

Bounds	HMC_M	HMC_L	ORD_H	ORD_M	ORD_L	BTC_H	BTC_M	BTC_L	COL_H	COL_M	COL_L
in_lower	86%	100%	79%	85%	92%	88%	94%	100%	75%	89%	93%
in_upper	86%	88%	100%	85%	85%	88%	82%	100%	83%	92%	83%
in_box	71%	88%	79%	69%	77%	75%	82%	100%	58%	81%	77%

The results in Table 3 and Table 4 indicate that the fidelity of the look-up table varies. Generally, with higher flows, the predictive accuracy decreases. This is likely because higher flows generally have higher velocities and larger transport distances.

Figure 1 indicates how the predictive accuracy varies with transport time and location on the Sacramento River. Generally, as the travel time increases, and thus transport distance increases, the predictive accuracy decreases. This is consistent with the findings in Table 3 and Table 4. Figure 1 also indicates a slight negative bias in the results, meaning that the actual transport distance is often slightly larger than the predicted transport distance (i.e., the mannequin was further downstream than predicted).

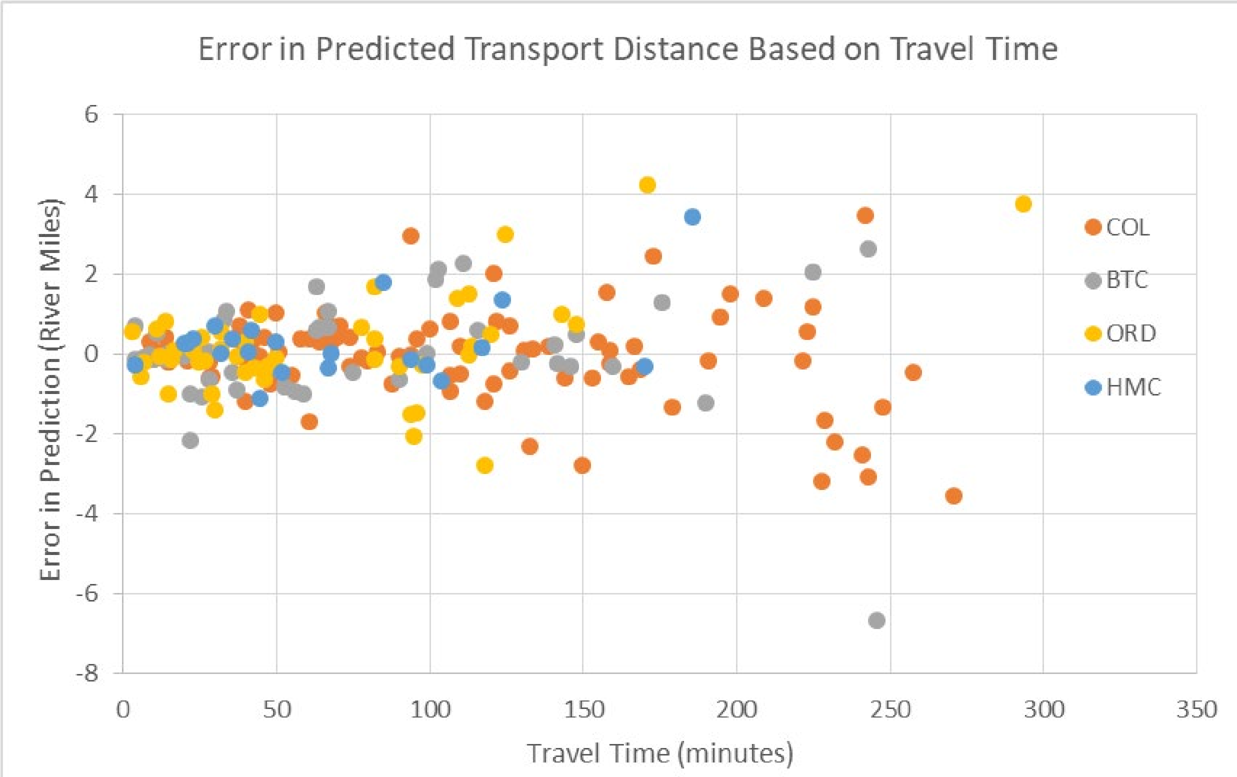

Figure 1. Error in predicted transport distance compared to actual transport distance for the 206 cross-validation data as a function of travel time. Negative values indicate the actual body location is further downstream than the predicted location. Positive values indicate the predicted location is further downstream than the actual location. Legend indicates location (Hamilton City = HMC; Ord Ferry = ORD; Butte City = BTC; and Colusa = COL)

The transport simulations used to develop the look-up table assume free transport of the body. Therefore, a major factor affecting the predictive accuracy are snags and other impediments (e.g. caught in an eddy) that prevent the body from flowing freely downstream. Of the 206 cases used in the cross-validation analysis, 180 were snagged or impeded (Appendix R), 24 were still drifting freely when the trial was stopped, and 1 was undocumented. Table 5 provides a summary of the trials that were snagged based on location and flow.

Table 5. Percentage of the 205 cross-validation data where documented snags or impediments to free transport occurred. Columns indicate location (Hamilton City = HMC; Ord Ferry = ORD; Butte City = BTC; and Colusa = COL) and flow condition (low=L; medium=M; and high=H). There were no cross-validation data for Hamilton City under high flow conditions.

Snagged/ Impeded	HMC_M	HMC_L	ORD_H	ORD_M	ORD_L	BTC_H	BTC_M	BTC_L	COL_H	COL_M	COL_L
Yes	93%	100%	89%	100%	100%	94%	76%	93%	71%	92%	80%
No	7%	0%	11%	0%	0%	6%	24%	7%	29%	8%	20%

Results in Table 5 indicate that approximately 90% of the trials were snagged or impeded. While some locations experienced more snags than others (e.g., ORD vs COL), there was not a consistent trend related to flow condition (low vs medium vs high flows). Many natural snags, such as woody debris, are dynamic and can move around from year-to-year. Furthermore, whether a body will get caught in the snag versus drifting around is highly dependent on flow conditions in the immediate vicinity of the snag (within a few feet). These characteristics make incorporating snags and similar impediments into a predictive model intractable. Nevertheless, these results indicate the important role that snags and other impediments play in transport of human remains and a limitation of the transport modeling used in this work.

Sac River Search

Sac River Search is a predictive web-based tool that assists in the location and recovery of deceased persons (Appendix O). The application runs on both desktop and mobile platforms, allowing for use in different scenarios. Currently, it is optimized to run on Google Chrome and will be expanded to other browsers in the near future. Login and password credentials will be made available to local law enforcement and search and rescue organizations that work in the study area. To gain access to the application please contact Drs. Eric Bartelink at ebartelink@csuchico.edu or Colleen Milligan at cfmilligan@csuchico.edu of Chico State's

Human Identification Laboratory. Additionally, data can be submitted for processing in the application for those that do not have site permissions using the emails above. When submitting data, provide the date and time the victim went into the water along with the approximate location (using local landmarks).

The application provides three main visual features to assist with probable locations for recovery: 1) a Search Box (green river buffer) that estimates the probable stretch of river that a body would be found in with no interference from natural or human features in the river; 2). a Predicted Location (yellow dot) that estimates the probable location of a body that is transported with no interference from natural or human features in the river; and 3) an Upriver Search Box (red river buffer) estimates the probable stretch of river that a body would be found in where there was some sort of interference during transport. Interferences could include natural strainers, snags, grounding out, river eddies, or human infrastructure (pumps, fish traps, etc.).

To use the predictive tool, the end user must know what river mile the victim went in the river, how long the body has been transported, and the river flows when the body started transport in cubic feet per second (cfs). River miles can be acquired from the predictive tool using the labels or by clicking on a section of the river. The river has been broken down into half-mile segments, starting at river mile 90 near Verona and going up to river mile 199, near Hamilton City. Determining minutes of travel (30-minute increments) can be a challenge as transport typically only starts after a victim has drowned and decomposition has started, when gasses from within the body cause it to float. This typically takes two to three days based on the water temperature. If this amount of time has not passed, searchers should focus their efforts close to the location where the victim went into the water. If two or three days have passed, then the end user will need to input the amount of transport time in minutes. The final item that the end user must input is the river flow. The data can be pulled from the California Data Exchange Center (CDEC) https://cdec.water.ca.gov. Navigate to River Conditions and then to the Hamilton City (HMC) gauge for cfs. It is advised to use the Daily Data that can be accessed at the bottom of the page for any given gauge. Use Hamilton City (HMC) for all entry points between the Highway 32 bridge near Hamilton City downstream to the confluence of the Feather River near Verona. If the Hamilton City gauge is offline during an event, the user should use the next closest upriver gauge (ORD) for the flow regime. In the event that multiple gauges are out, use BTC followed by COL as necessary.

The search icon allows the end user to search for the appropriate prediction scenarios by inputting the information previously discussed. The end user can customize the look of the map by choosing the Maps icon and changing the base map to imagery or other stock backdrops. The info icon will bring up a user guide and a copy of the disclaimer text that the user previously agreed to. On the map pane, the end user can use the Location symbol to find their location when in the field (need a mobile device to be online). The plus and negative symbols allow the user to zoom in and out. The house symbol allows the user to recenter the map for the study area. Additional functionality, which is currently in the process of being developed, will include the layers icon which will allow you to add reference layers such as river miles, gauge locations, etc. An export function will also be added that allows a Geopdf of the predicted search information to be created and downloaded. It can be consumed in a mobile application like Avanza Maps (https://www.avenza.com/) to navigate, off or online, through the exported geography.

It should be noted that the search box and prediction are based on unimpeded transport. Any snags, strandings, or other occurrences that change the rate of transport may make the predicted location inaccurate. The entire search box should be considered when attempting to locate a victim. In addition, the prediction only addresses fluvial transport of floating bodies, so an estimate of the submerged interval needs to be factored into the search process. The taphonomic literature suggests that most bodies will begin to float by the second to third day postmortem, although this can take as long as five days in cold water conditions, such as deepwater lakes (Lunetta et al. 2014). Future research will specifically examine the submerged interval in the Sacramento River using nonhuman exemplars to test the influence of temperature on the build up of decompositional gases.

Sac River Search will be maintained and made available by the principal investigators for the foreseeable future. It will be embedded in a home page for the project that will be hosted by the North State Planning and Development Collective at Chico State. Additional functionality may be added based on feedback from local law enforcement agencies, principal investigators, and others involved in the project.

Sac River Search: Case Study

Historical case research produced 64 records in the Sacramento Valley area for body recoveries. Of those, only 14 had a component of entry or exit in our study area. Additionally, only six of the fourteen entries have a full set of records that includes the date and location of entry to the river, hours/days in the river, and the date and location of exit of the river. Further complicating the testing of the predictive tool, only 1 of those records had a total time in the river that fell within our time parameters and the geographical coverage of the model.

We used the one record that met our criteria and ran it through the *Sac River Search* predictive application (Appendix Q). The body was in the river for a total of 6 days between the date listed as entry and the date listed as recovered. We assumed, based on the typical time between entry and transport, that the body would have been in the river approximately four days before transportation. The remaining two days were applied to the minutes of transport. Using historic CDEC gauging station information for the date of entry, we found that the average flow was approximately 6,000 cfs.

All parameters were applied to the predictive application. The results showed that the potential for travel was large given the flows and time in the river. Free transport was predicted to be between seventy-three miles and eighty-eight miles, with a predicted location to be eighty and a half miles from the entry point. The actual distance traveled based on the recovery location was approximately one mile. The large discrepancy in distance traveled may be explained by interferences such as natural strainers, snags, grounding out, river eddies, or human infrastructure (pumps, fish traps, etc.). As noted in other sections of this report, the predictions are based on unimpeded fluvial transport and snags and other impediments commonly affect transport.

GPS Data Logger Animations

A visual aid was created as a byproduct of the GPS data logger recordings. For each successful recording, the resultant recording data was animated to demonstrate how the mannequin proceeded downriver (Appendix P). The web-based animations are set to run at speeds ranging from 10x to 1000x. You can simulate a single event or run multiple events in a given stretch to compare transport at the different recorded flows. Additionally, the symbolization of the transport changes based on recorded information such as In Transit, In Eddy, Intervention, Stranded, Transit Start, Transit Terminated, and Lost Communication. The user can view flow information for each event including Release Id, Coordinates, Date and Time, Flow, Release

Weather, Distance Traveled, and Category. This information is derived directly from the field sheets and data collected for the release.

Currently, the animations are for internal use. We plan to make them available to local law enforcement and search and rescue organizations to help them better visualize how bodies can transport downriver and how features such as gravel bars, eddies, and snags can change the rate of transport. Access to the animations is available upon request. Please contact Drs. Eric Bartelink at ebartelink@csuchico.edu or Colleen Milligan at cfmilligan@csuchico.edu of Chico State's Human Identification Laboratory for access.

Dissemination of Results

The results of this study have been disseminated to the forensic science and forensic anthropology community through presentations at the annual meetings of the *American Academy of Forensic Sciences* (2019), the *National Institute of Justice Research Symposium* (2020) in conjunction with the *AAFS*, and the *Mountain, Desert, and Coastal Forensic Anthropologists Meetings* (2017). The research has also been presented to the California Department of Justice's *Missing and Unidentified Persons (MUPS) Conference* (2018), the California Peace Officers Standards and Training's *ICI Homicide Investigations* courses (2016-2022), the *California State Coroner's Conference* (2019), to the *Yolo County Sheriff's Office* (2022), and the *California Rural Crime Prevention Task Force* (2022). The research team also conducted a training day on the Sacramento River in conjunction with Sutter County's Sheriff's Office boat team. We plan to present on our completed research project, including *the Sac River Search* app, at both academic conferences and to law enforcement and search and rescue personnel.

In addition to the development of the web-based and mobile app, training events on the Sacramento River will continue, along with workshop training days for law enforcement and search and rescue teams. The results of this research will be published in journals aimed at specific audiences. We plan on submitting at least two papers to the *Journal of Forensic Sciences* based on this research, including an article that examines fluvial transport rates from our historical data set of river victims, as well as an article that tests the web-based predictive model against both the historic case and rescue mannequin data. We also intend to submit an article focused on best practices for river searches to other journals, such as *Forensic Science Policy & Management: An International Journal*, or *Science and Justice*. Finally, we plan to submit an article intended to reach the search and rescue audience, such as *Journal of Emergency Management, Disaster Medicine and Public Health Preparedness, Journal of Search and Rescue, or Journal of Homeland Security and Emergency Management*.

Future Research

The current project has significantly advanced our understanding of the fluvial transport of human remains in the Sacramento River. The *Sac River Search* prediction app will provide useful search parameters for law enforcement and search and rescue teams to confine their search area for river victims, saving both time and expense. There were many challenges in conducting this research. This included limitations using the US Army Corps of Engineers HEC-RAS model, limitations in historical case information provided from law enforcement agencies, logistical issues of working within a dynamic fluvial environment, understanding the timing of the postmortem submerged interval, and the impact of snags and other obstructions on the transport of the rescue mannequins.

The HEC-RAS model was not user ready for this project, and required significant modifications to create reasonably accurate simulations of the flow for the range of conditions tested. The model used only could be applied to a section of the river (Glenn County to northern Yolo County), as a different, more complex HEC-RAS model would need to be used for the areas south of the river (i.e., southern Yolo and Sacramento Counties). The southern portions of the river are more complex to model due to inputs from the Feather River and American River. Future research could adapt a different HEC-RAS model to this area, which also happens to be the location where most river deaths occur.

Although law enforcement agencies were very willing to share case information, many of the reports were from the 1970s-1990s. Case information was often very incomplete, and most files lacked sufficient detail identifying where and when a person entered the river. More recent cases often have GPS coordinates and more complete files. We plan to provide a data collection sheet to agencies in our project area that will facilitate the use of the *Sac River Search* app.

The Sacramento River is a complex and dynamic fluvial system. Although we exceeded the number of field trials originally proposed, it was not always possible to capture adequate flow data for every location due to timing issues associated with flow rates (e.g., treacherous conditions on the river, COVID-19 restrictions). Under very high flow rate conditions, it was difficult to recover the rescue mannequins safely, especially if they were caught on a snag or other obstructions. Also, conducting the transport tests using the sinker mannequins required personnel to be in the river up to waist-deep. Only low flow and low-medium flows could be conducted safely. We plan to explore transport rates within the water column using our prototype of the neutral buoyancy mannequin in future studies to create a more realistic model for submerged transport.

The current study only focused on the use of rescue mannequins (floaters and sinkers), so we did not have a way to evaluate the length of the submerged interval. Historical case data and published literature suggest that most dead bodies in rivers will begin to float within 2-3 days following deposition, with slightly longer intervals (3-5 days) for cooler waters. We plan to test this in future studies using nonhuman exemplars. Thus, the *Sac River Search* app is limited to transport occurring at the surface (when the body has begun to float following the submerged interval). Finally, the majority of the floater mannequin transport runs involved snagging. Thus, mannequins were commonly caught on obstructions, such as snags of trees and fish traps. This issue calls to attention that the search box used assumes free transport, and that search and rescue teams must also include the entire transport area to search possible snagging locations.

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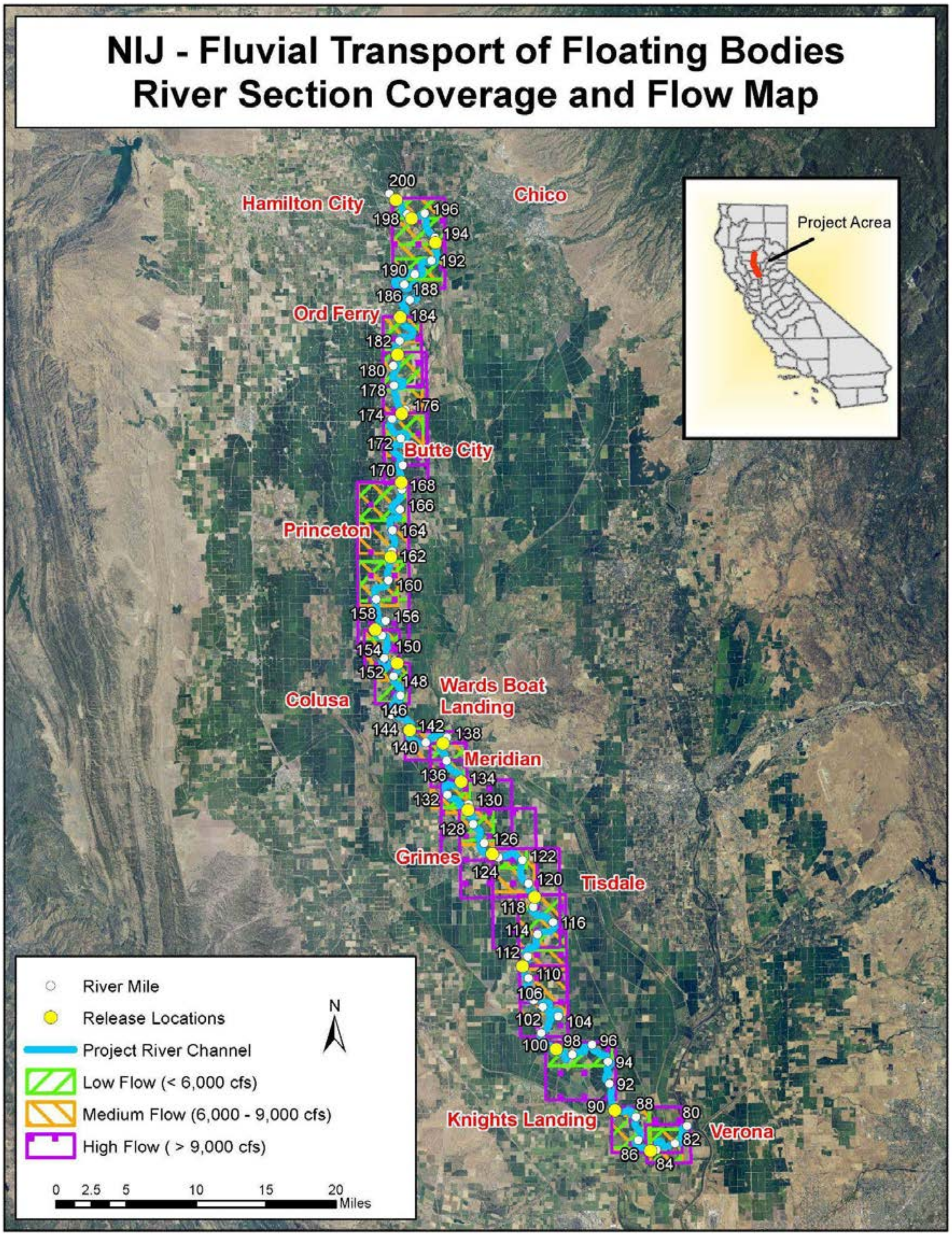
Poeter, EP., Hill, MC, Lu, D., Tiedeman, CR, and Mehl, S. 2014, UCODE_2014, with new capabilities to define parameters unique to predictions, calculate weights using simulated values, estimate parameters with SVD, evaluate uncertainty with MCMC, and More: Integrated Groundwater Modeling Center Report Number: GWMI 2014-02.

APPENDICES

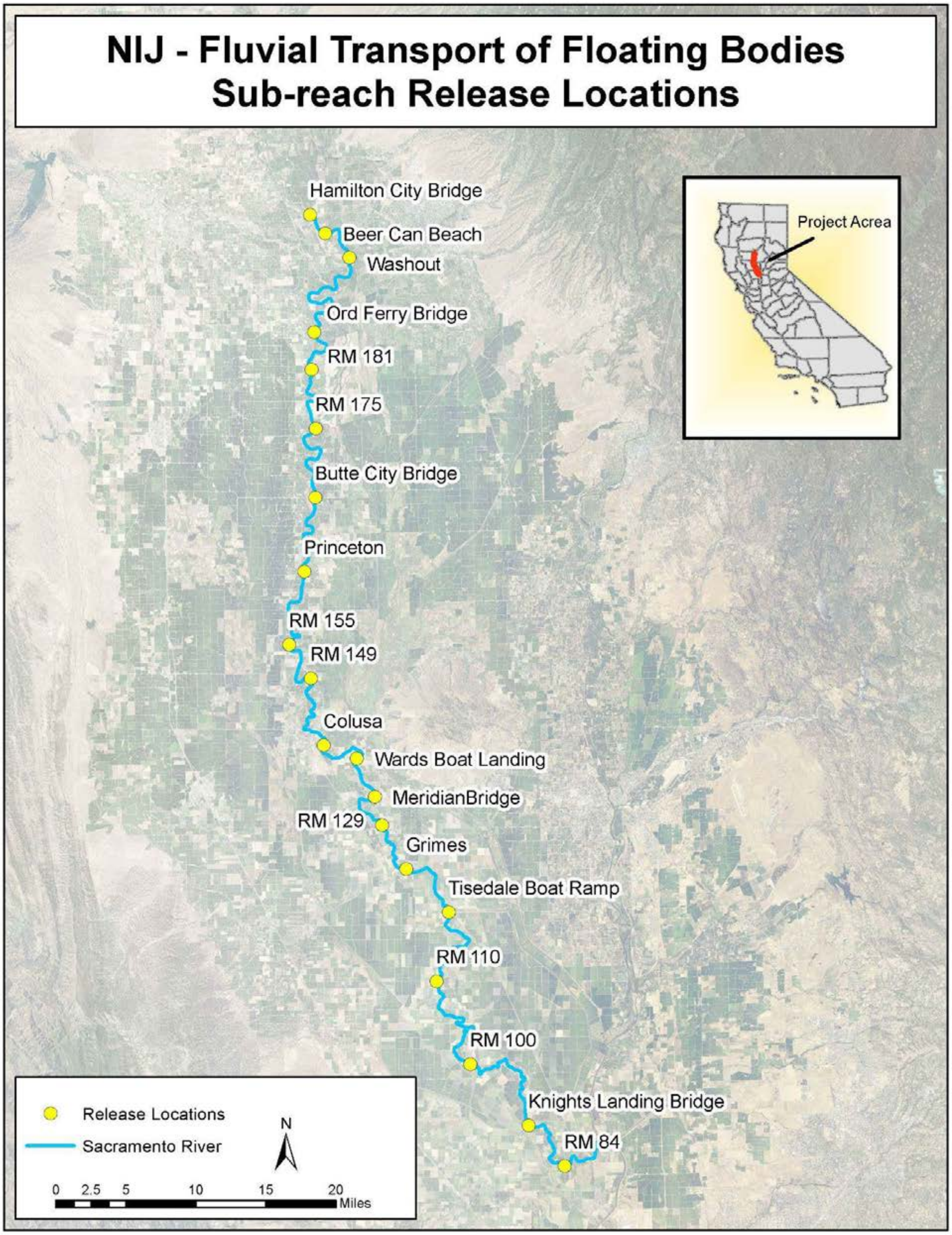
Appendix A: Map of the Project Area

Appendix B : Map of River Section Coverage and Flow



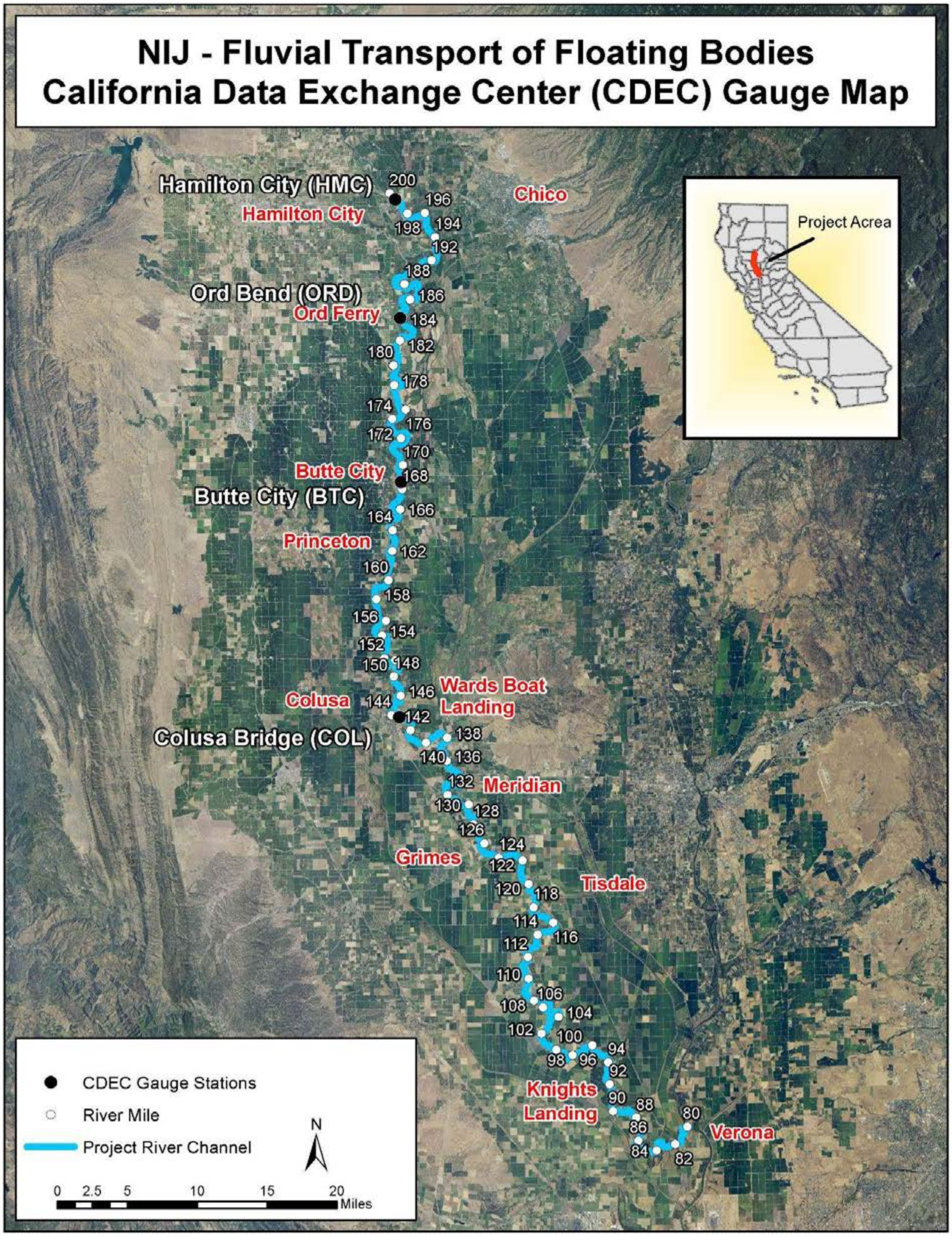
Appendix C: Ruth Lee Rescue Mannequins (Left = Sinker; Right = Floater)

Appendix D: Map of Sub-reach Release Locations

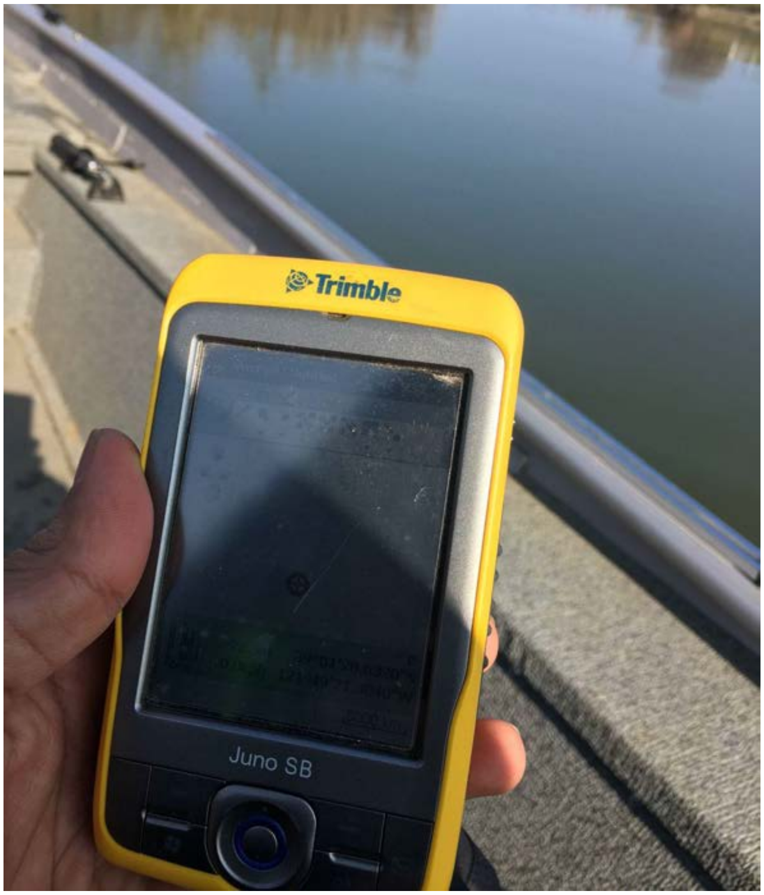


Appendix E: Radio Transmitter and Receiver

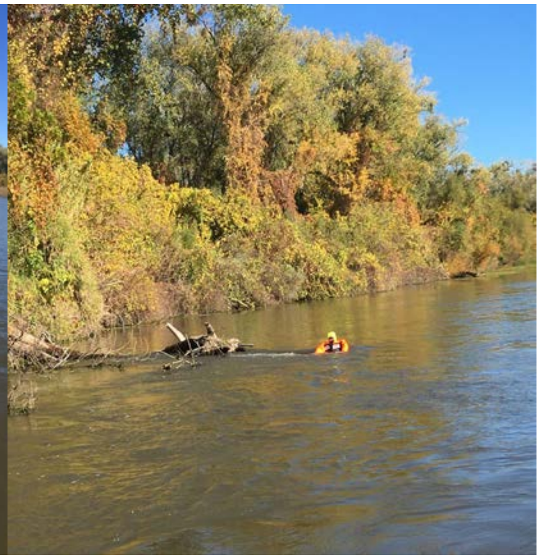
Appendix F: Map of CDEC Gauge Stations



Appendix G: GPS Receiver and Data Logger



Appendix H: Floater Mannequin Trials



Appendix I: Floater Mannequin Data Collection Sheet

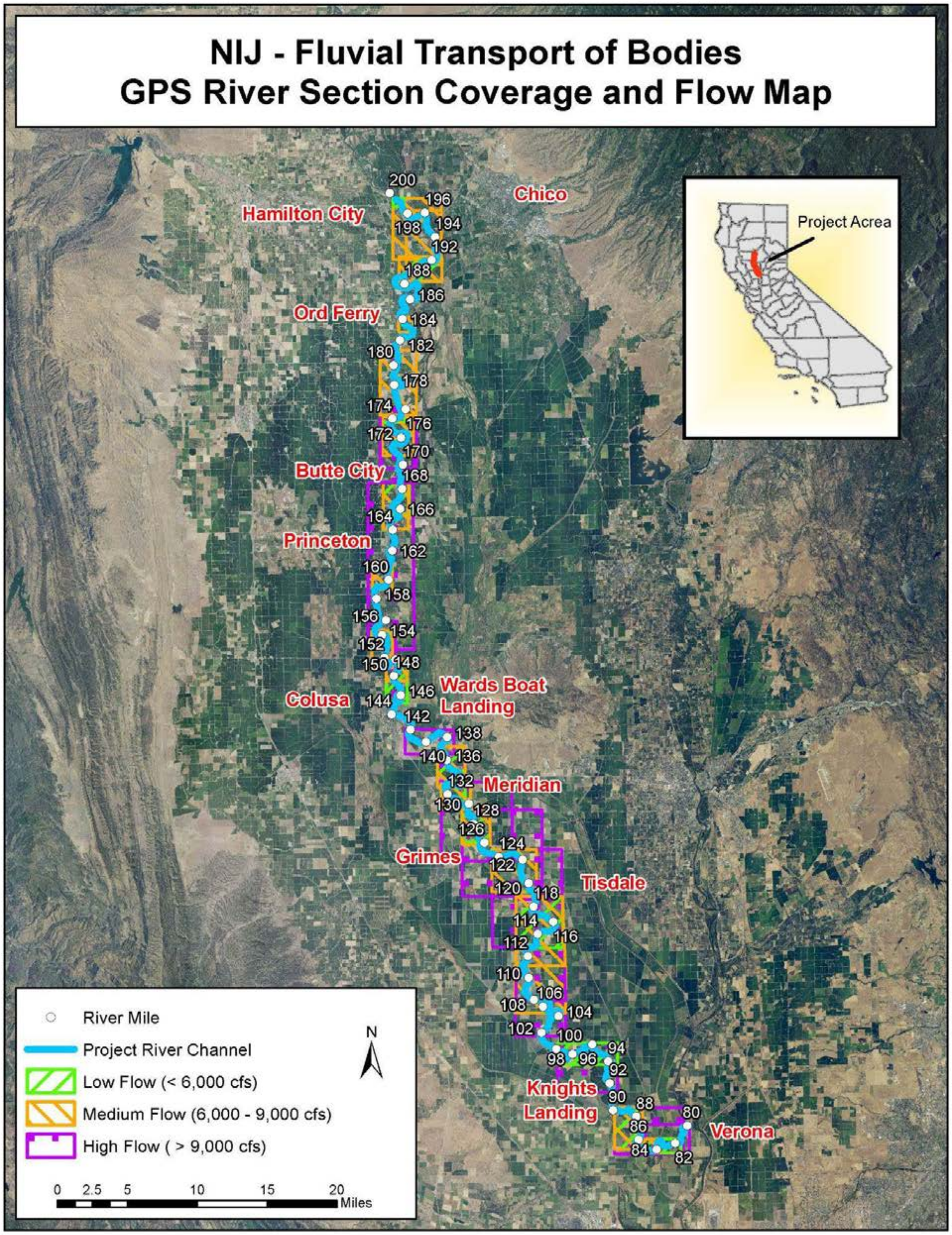
Start Date	Manniquin #	RF Tag#	GPS Tag#/None	Crew

Release ID#	Side	Time		Lat	Long	PDOP	Wind Dir	Wind MPH
Release Comments								
Recovery ID#	Side	Time	Standed Time	Lat	Long	PDOP	Wind Dir	Wind MPH
Recovery Comments								

Release ID#	Side	Time		Lat	Long	PDOP	Wind Dir	Wind MPH
Release Comments								
Recovery ID#	Side	Time	Standed Time	Lat	Long	PDOP	Wind Dir	Wind MPH
Recovery Comments								

Field Observations

Appendix J: Map of GPS River Section Coverage and Flow



Appendix K: SonTek FlowTracker

Appendix L: Sinker Mannequin Data Collection Sheet

Start Date	Manniquin #	Crew

Lat	Long	Depth	Velocity (1ft)	Substarte	Comments

Start Date	Manniquin #	Crew

Lat	Long	Depth	Velocity (1ft)	Substarte	Comments

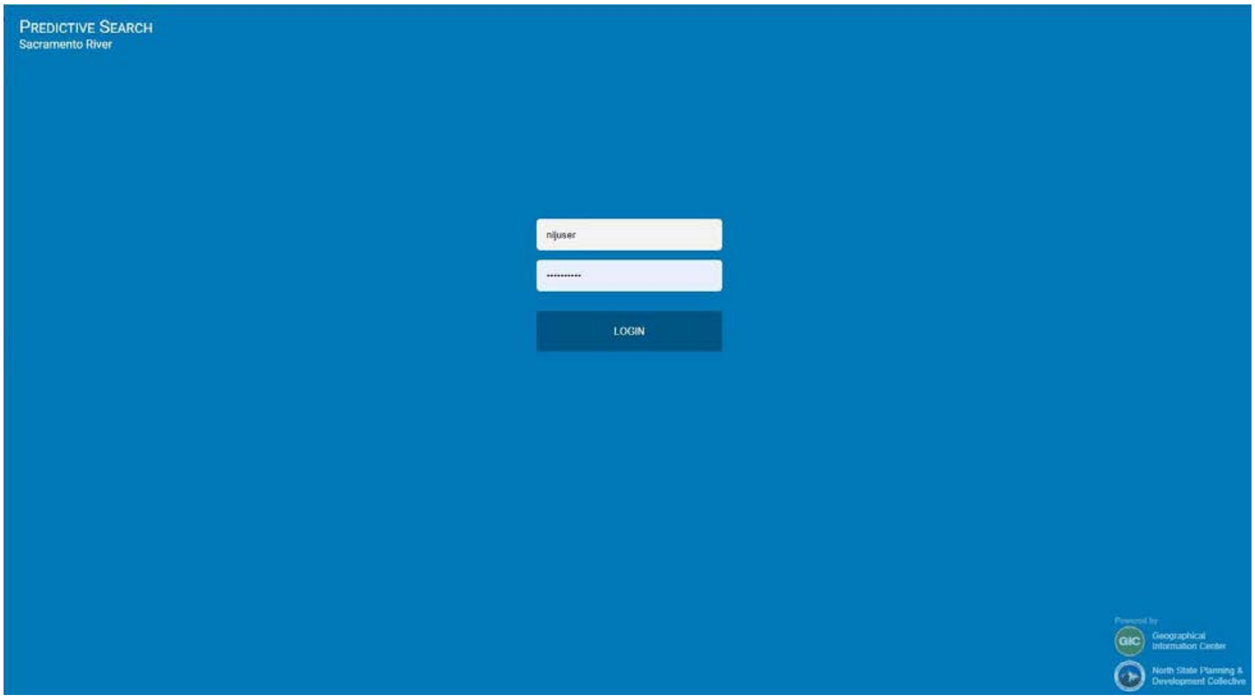
Start Date	Manniquin #	Crew

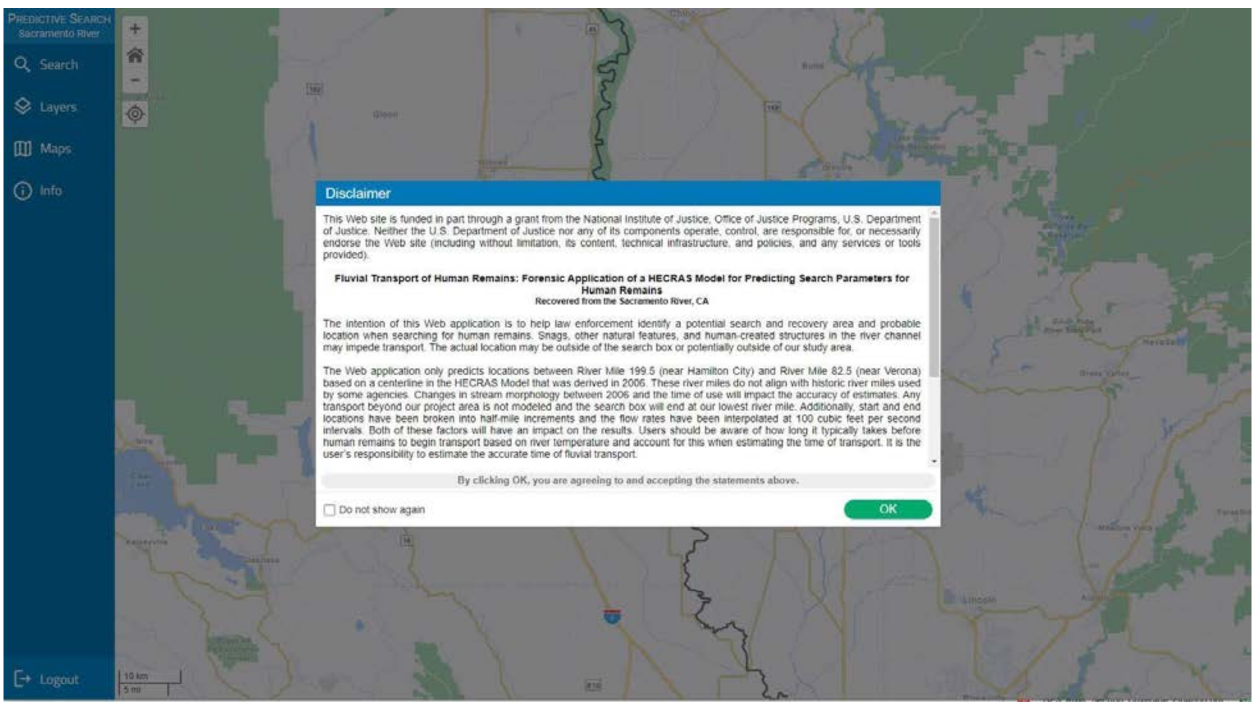
Lat	Long	Depth	Velocity (1ft)	Substarte	Comments

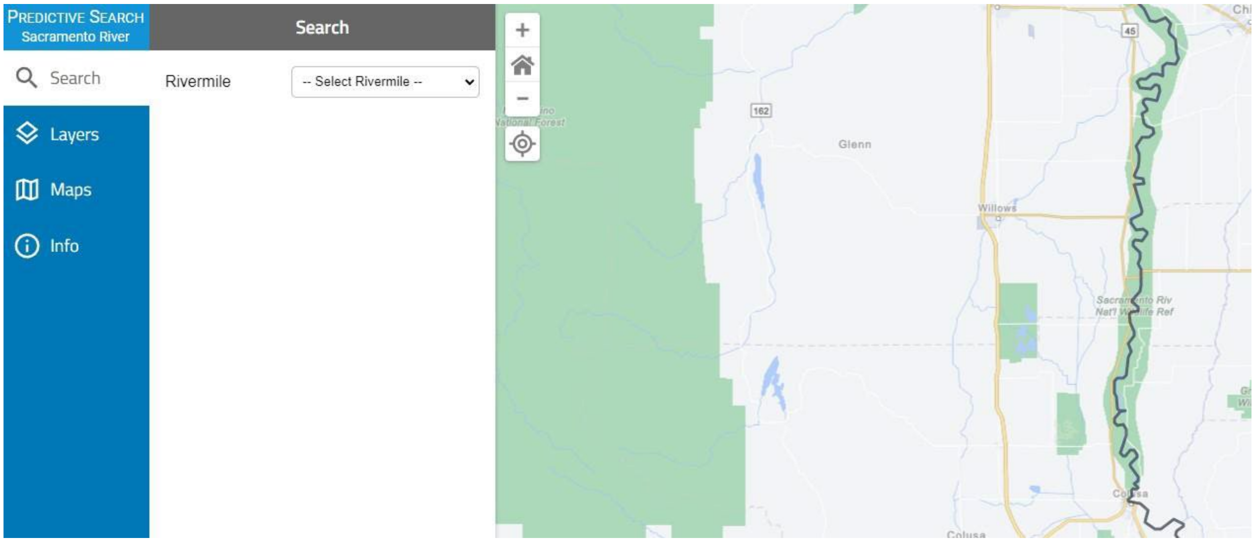
Appendix M: Sinker Testing

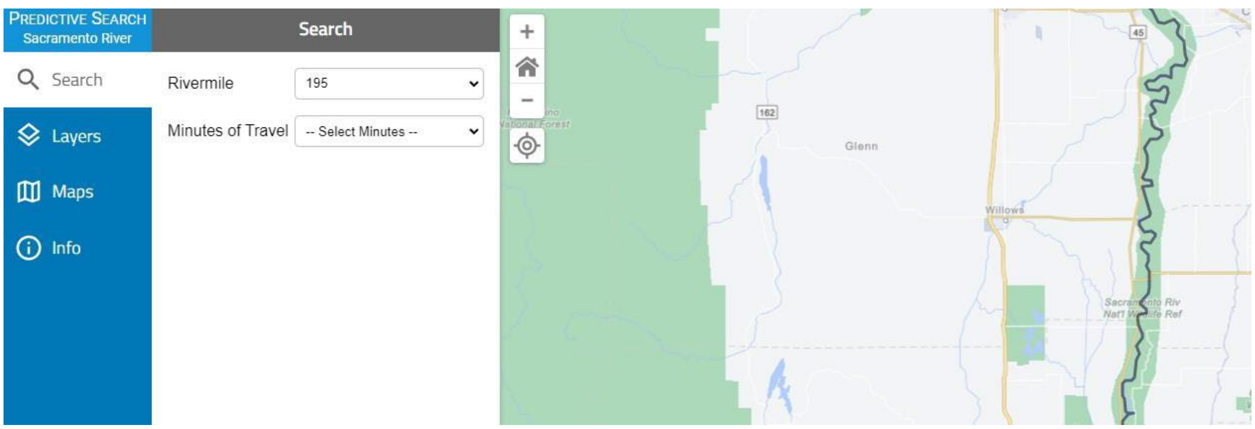
Appendix N: Variation in Substrates for Sinker Dummy Locations

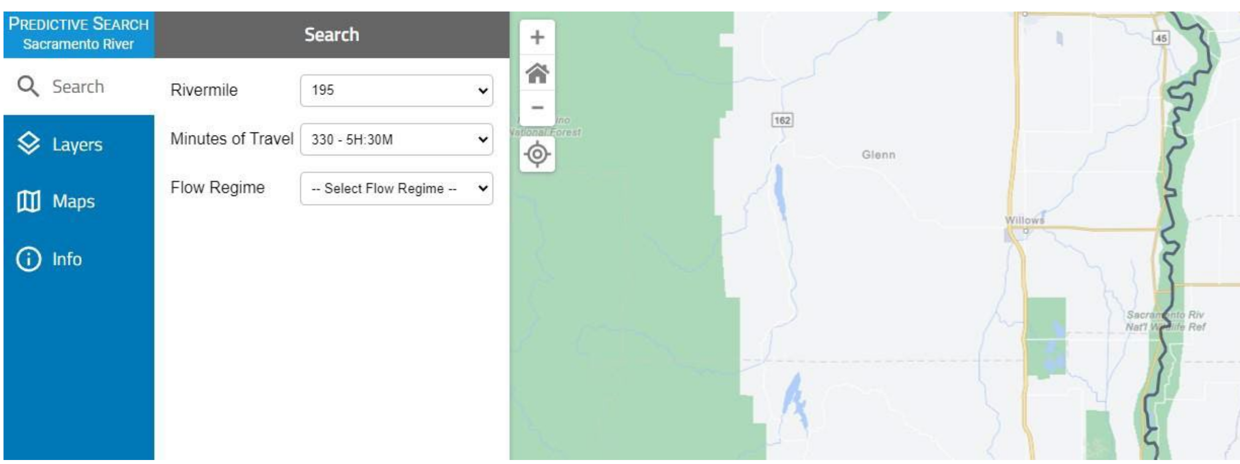
Appendix O: *Sac River Search Application*

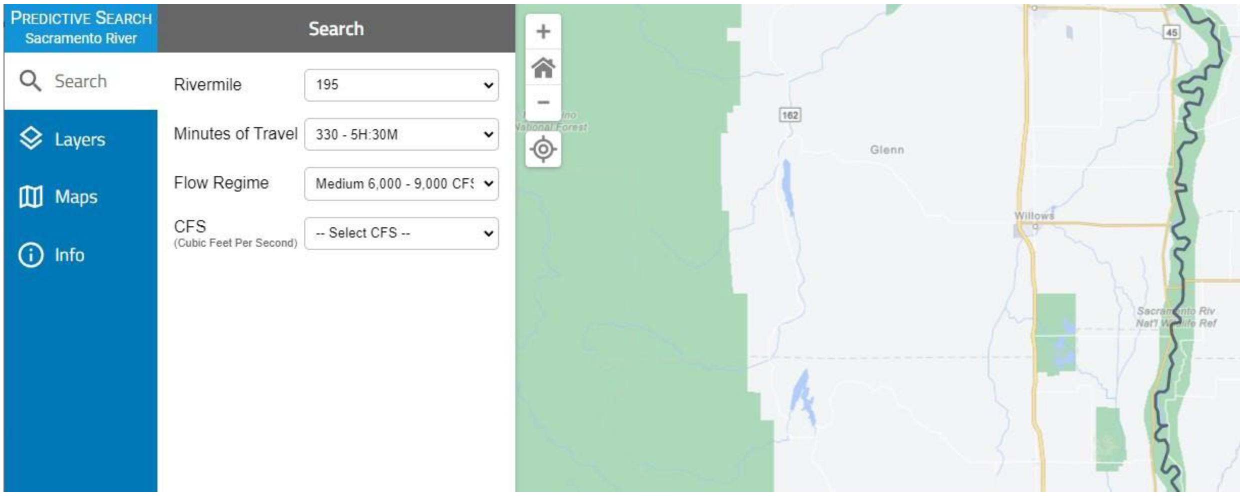


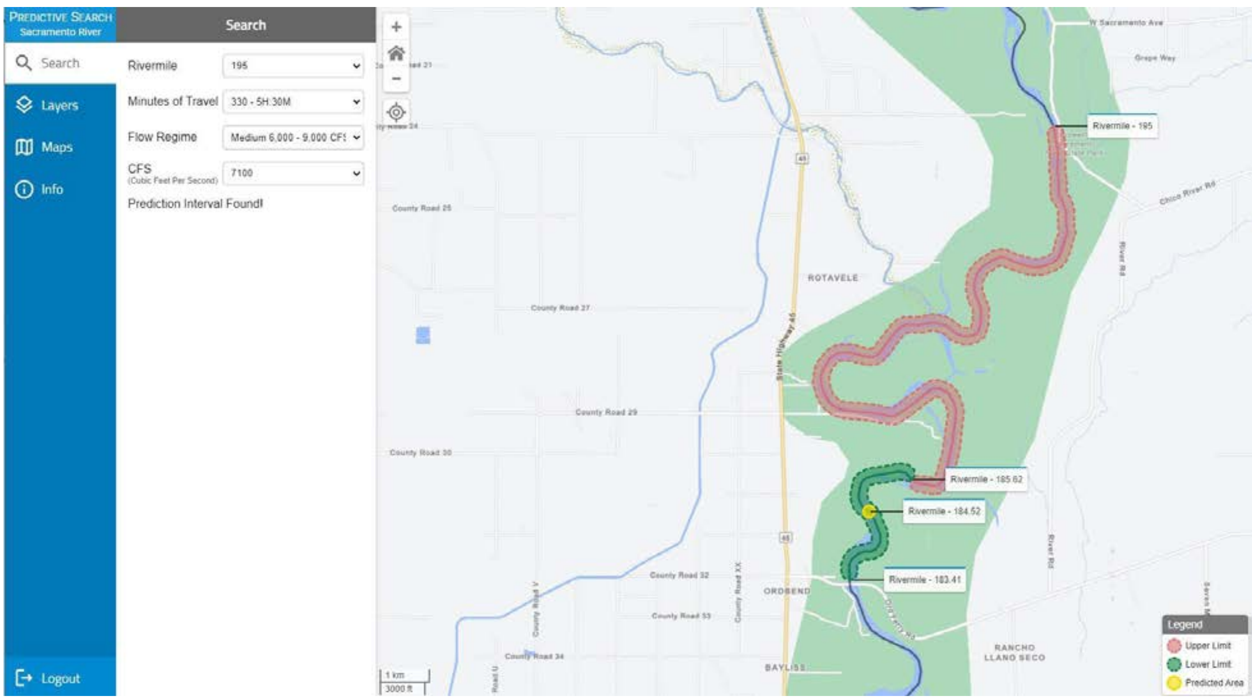



PREDICTIVE SEARCH
Sacramento River
Search
Search
Layers
Maps
Info
Rivermile
-- Select Rivermile --
Glenn
Willows


PREDICTIVE SEARCH
Sacramento River
Search
Search
Layers
Maps
Info
Rivermile
195
Minutes of Travel
-- Select Minutes --
Glenn
Willows


PREDICTIVE SEARCH
Sacramento River
Search
Search
Layers
Maps
Info
Rivermile
195
Minutes of Travel
330 - 5H:30M
Flow Regime
-- Select Flow Regime --
Glenn
Willows





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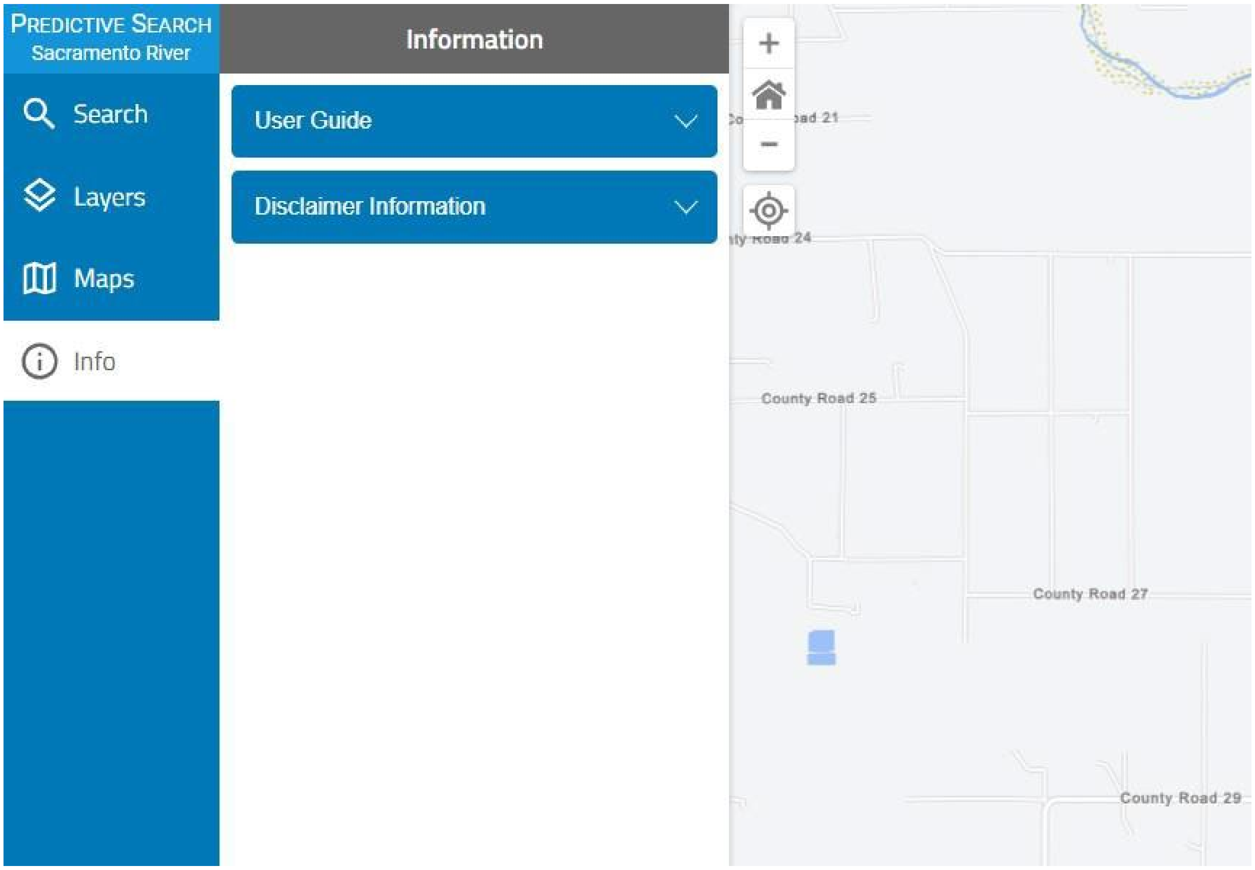
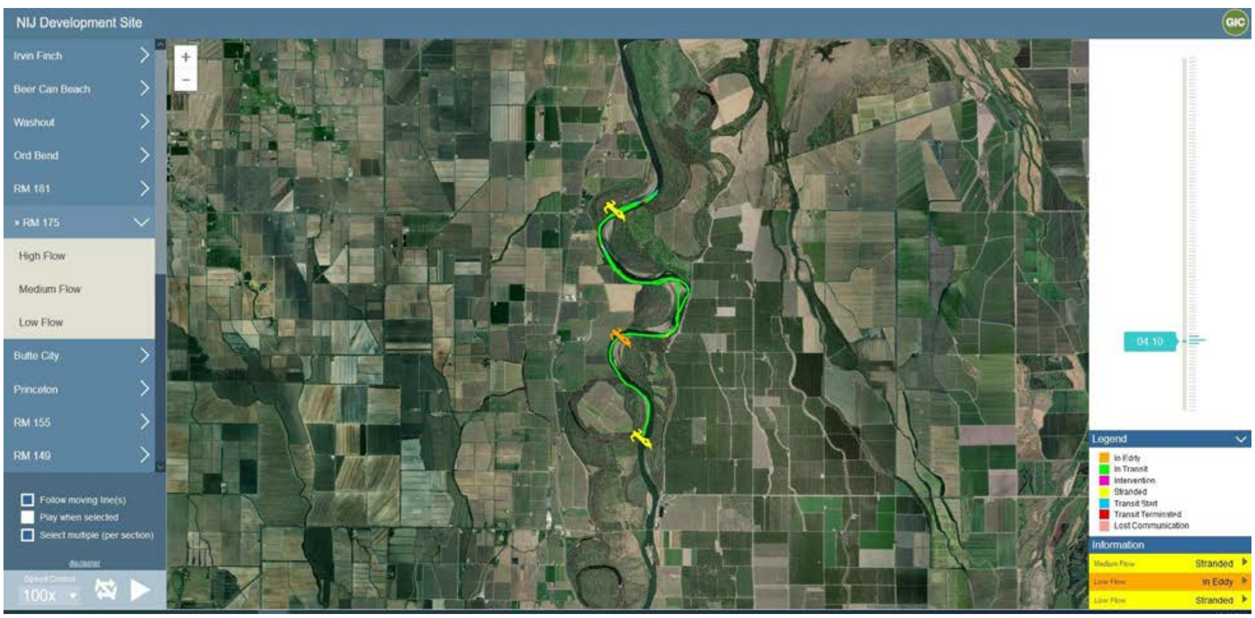
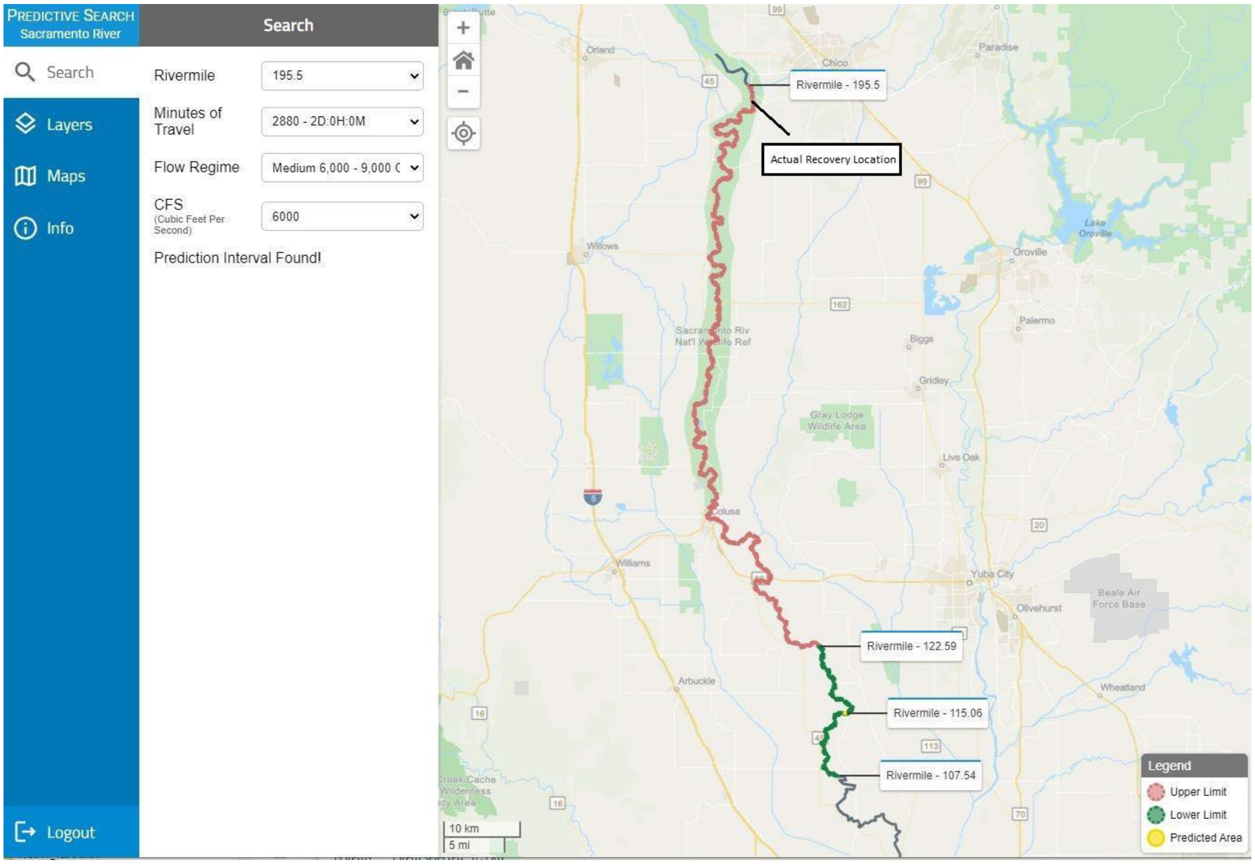

PREDICTIVE SEARCH
Sacramento River
Search
Layers
Maps
Info
Information
User Guide
Disclaimer Information
County Road 25
County Road 27
County Road 29

Appendix P: Animation Examples

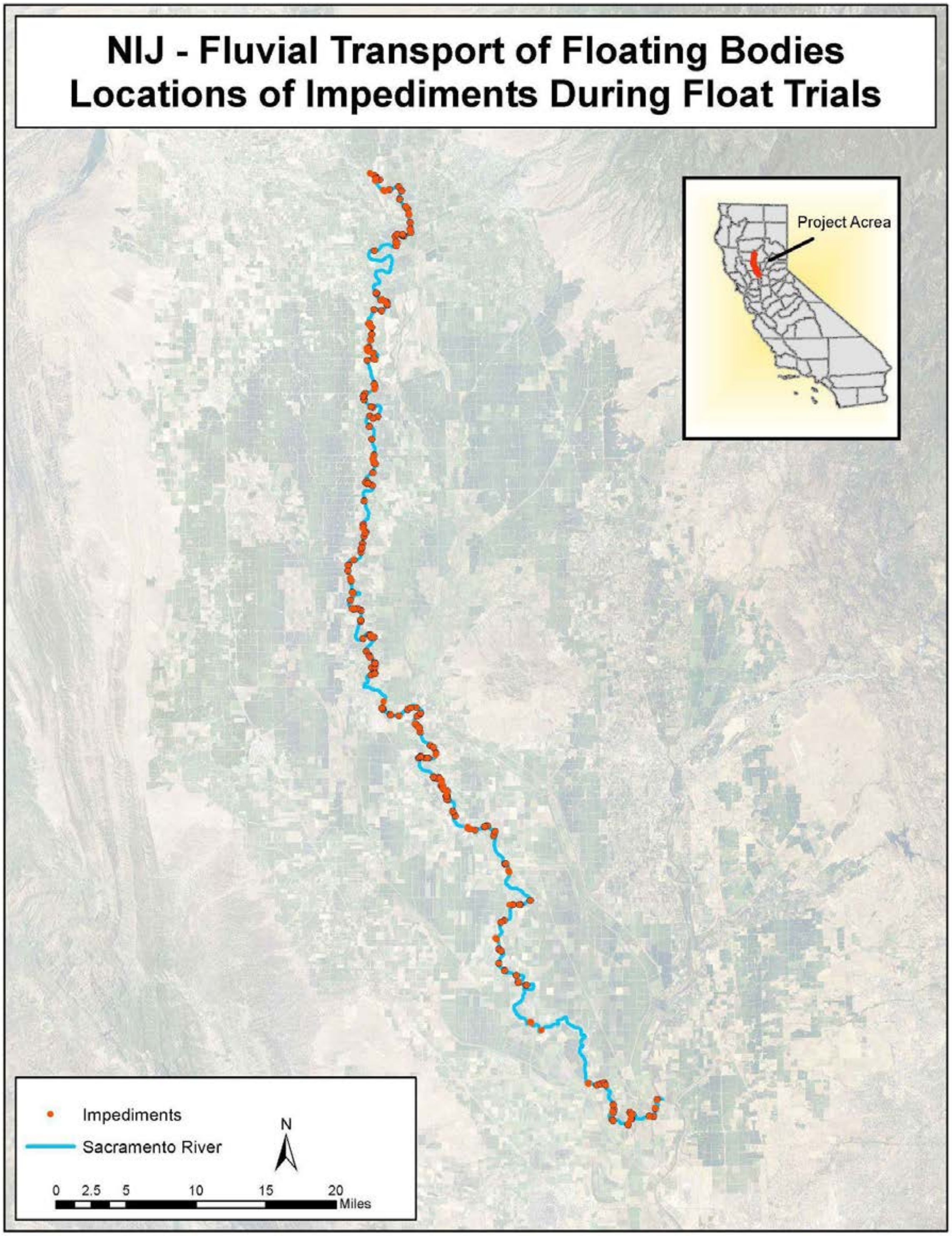

NIJ Development Site
Colusa
Wards Landing
Meridian Bridge
RM 129
Grimes
Tisdale
RM 110
RM 100
Knights Landing
RM 84
High Flow
Medium Flow
Low Flow
Follow moving line(s)
Play when selected
Select multiple (per section)
Speed Control
1000x
02:52
Legend
In Eddy
In Transit
Intervention
Stranded
Transit Start
Transit Terminated
Lost Communication
Information
Low Flow
In Eddy
Medium Flow
Stranded

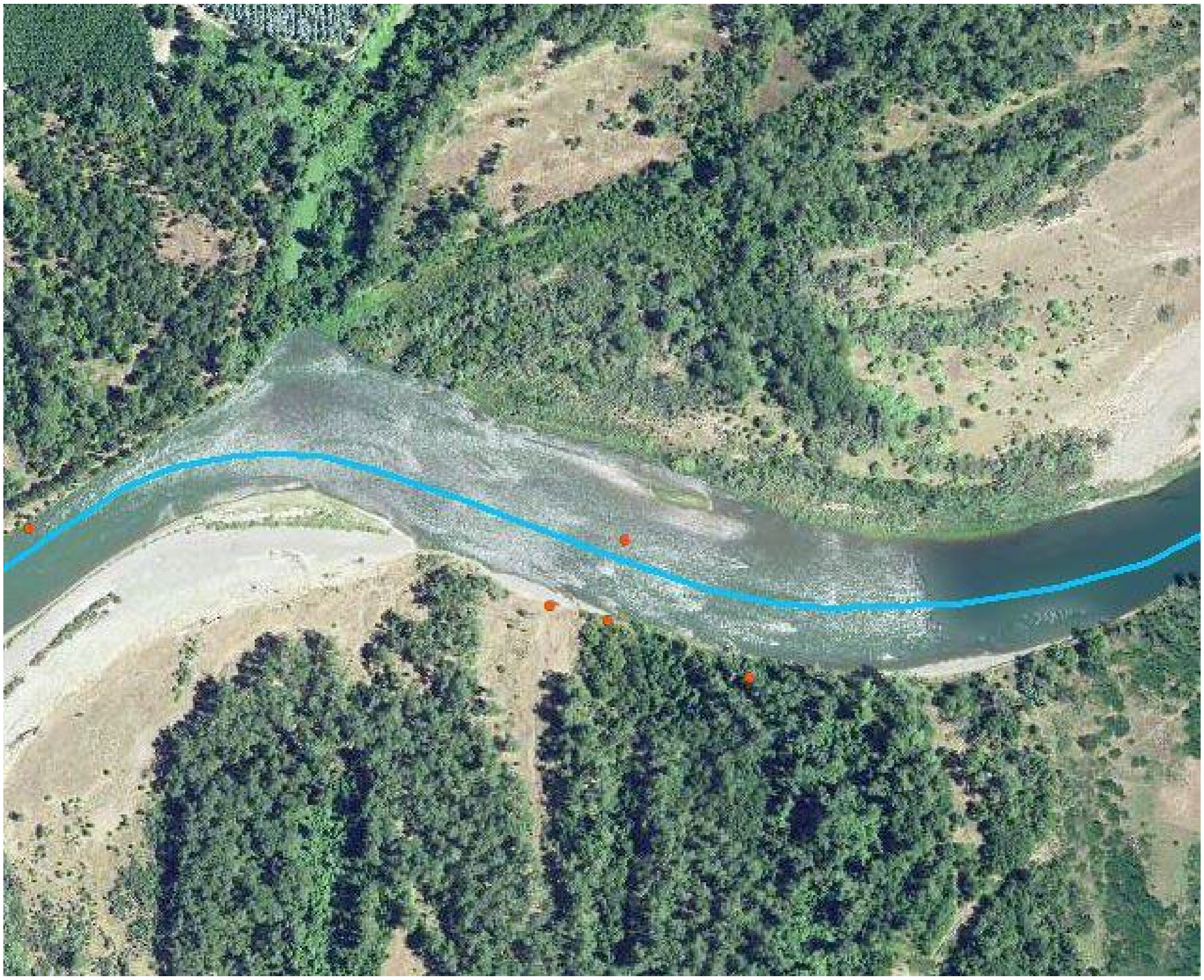

NIJ Development Site
Irvin Finch
Beer Can Beach
Washout
Ord Bend
RM 181
RM 175
High Flow
Medium Flow
Low Flow
Butte City
Princeton
RM 155
RM 149
Follow moving line(s)
Play when selected
Select multiple (per section)
100x
04:10
Legend
Information
Stranded
In Eddy
Stranded

Appendix Q: *Sac River Search* Case Study



Appendix R: Impediment Locations and Examples





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