LOWER SPOKANE RIVER REDBAND TROUT SPAWNING HABITAT: MONROE STREET DAM TO NINE MILE DAM POOL

SPOKANE RIVER HYDROELECTRIC PROJECT FERC PROJECT NO. 2545

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1.0 INTRODUCTION

Avista Corporation (Avista) owns and operates the Spokane River Hydroelectric Project in eastern Washington and northern Idaho. On June 18, 2009, the Federal Energy Regulatory Commission (FERC) issued a new License (License) for the Spokane River Hydroelectric Project (FERC order 2009). Paragraph E of the License incorporated the *Washington Department of Ecology (Ecology) Certification Conditions Under Section 401 of the Federal Clean Water Act (Issued on May 8, 2009 and amended on May 11, 200*9). These conditions can be found in Appendix B of the License. The purpose of this study is to comply with conditions in section 5.3 (D) 2 (a, b, and c) of the License Appendix B, which state the following specific to native rainbow, or redband trout (*Oncorhynchus mykiss*) in the lower Spokane River:

1. Quantify the quality and quantity of trout spawning habitat: determine the most productive and least productive spawning areas by developing quality strata at all flow/discharge elevations.
2. Quantify spawn to emergence success: determine survival from egg to emergence by strata using artificial redd construction. Correlate egg-to-emergence survival for each stratum with corresponding flow/discharge and include velocity, depth, and temperature as variables.
3. Quantify redd dewatering at different flow/discharge elevations for each habitat quality stratum.

Avista consulted with the Washington Department of Fish and Wildlife (WDFW) and Ecology to select a study approach and contract team to conduct a two year Lower Spokane River (Monroe Street Dam to the Nine Mile Dam Pool) redband trout spawning study. Field work began in the fall of 2009 and concluded in early summer of 2010. Avista met with and provided WDFW and Ecology with an overview of preliminary draft results in late 2010. This report provides the final results of the study.

2.0 STUDY OBJECTIVES

The objectives of the spawning habitat study were as follows:

- Spatially map the quantity and quality of spawning gravel along the entire length of the study reach (Monroe Street Dam to Nine Mile Reservoir);
- Use empirical data to quantify spawning habitat and redd dewatering over a wide range of flows;
- Use artificial redds to assess the survival of eggs in different quality strata spawning patches and correlate survival with physical variables; and
- Develop a predictive spawning habitat and fry emergence model (effective habitat model) that can estimate the quantity and quality of spawning habitat over a wide range of flows.

Figure 1 includes the study objectives and elements and where information developed for this study is documented. It also shows where information developed is documented.

3.0 STUDY ELEMENTS

Study elements were initiated in fall 2009 and were completed in early 2011. They include the following:

- Historical hydrology review;
- Spawning patch inventory of the entire study area;
- Physical characterization of spawning patches, including delineation of patch polygons, characterization of patch elevations, and bulk gravel sampling;
- Hydrodynamic characterization of spawning patches, including development of stage-discharge relationships and empirical mapping of spawning habitat depths and velocities over a wide range of flows;
- Biological spawning characterization, including spawning surveys, habitat suitability criteria development, and artificial redd evaluation of selected spawning patches of differing quality; and
- Development of effective spawning and incubation habitat relationships over a wide range of flows based on spawning patch quality strata.

4.0 STUDY AREA

The study area is the approximately 10 mile free-flowing reach of the lower Spokane River from Monroe Street Dam, near River Mile (RM) 74 downstream to the Nine Mile Dam Pool near RM 64 in eastern Washington (Map 1). Hangman Creek, or Latah Creek as it is sometimes called, is the only tributary entering the study area (RM 72.2).

5.0 STUDY APPROACH

The study approach for the historical hydrology review, spawning patch characterization, biological spawning characterization, and effective spawning and incubation habitat quantification is provided below.

5.1. HYDROLOGY REVIEW

The historical hydrology (1980–2010) for the Spokane River at Spokane WA USGS Gage (No.12422500) (USGS Spokane River Gage) was plotted for each day (daily average flow in cubic feet per second (cfs)) and for the mean, median, 20% exceedance, and 80% exceedance daily discharges. The Spokane River Gage is located in the upper portion of the study area (RM72.82, Map 1). Historical hydrology is discussed in terms of typical Avista operations and Avista's capability to manipulate flow at the Upper Falls and Monroe Street hydroelectric developments (HED).

The historical hydrology data and stage-discharge data (USGS gage, NHC 2003) in the study reach was also used to guide the spawning patch inventory. The 20% exceedance discharge during spawning (April) (i.e., 80% of the time flows are less than this flow) was approximately 17,000 cfs. Based on the historic stage-discharge data, 17,000 cfs related to a stage approximately 6 feet above base flow in the river during the spawning patch inventory (approximately 1,200 cfs). A stage of approximately 6 feet above the base flow was, therefore, used to guide the upper elevation of spawning site inventory (see below).

5.2. Spawning Patch Characterization

The spawning patch characterization consisted of inventorying spawning patches, quantifying physical attributes, and quantifying hydrodynamic attributes.

5.2.1. Inventory

All potential spawning sites within the study reach were identified during base flow conditions using a step-wise approach. An initial reconnaissance trip was conducted on September 8–10, 2009. Observations of potential spawning habitat were made directly on aerial photographs to develop a comprehensive inventory of specific locations likely to contain spawning habitat. The reconnaissance involved walking both river banks, walking all side channels, and floating the wetted channel of the entire 10 mile river reach between the Monroe Street Dam and the Nine Mile Pool in an open-frame cataraft to inspect the channel substrate. This initial reconnaissance identified all areas of contiguous gravel exhibiting physical characteristics similar to previously identified spawning locations (Parametrix 2003) and within 6 feet vertical feet of the base flow elevations (approximately 1,200 cfs).

The potential of each of the preliminarily identified redband trout spawning locations was then assessed from September 16–19, 2009, based on surficial particle size, general gravel composition, overall patch dimensions, and channel location. Each potential spawning area was either accepted or rejected based on this assessment. The criteria for selecting suitable gravel patches are discussed below. All areas that were accepted were assigned an identification number (patch ID), sketched on a field datasheet, flagged, and delineated on the aerial photos to assist in reoccupation of the patch on subsequent visits.

Surficial Particle Size

Although there is no definitive particle size statistic universally considered suitable for trout spawning, the fisheries literature indicates that most trout spawning occurs in the medium to coarse gravel size range (based on the Udden-Wentworth scale) of 8–64 mm (Kondolf and Wolman 1993; Reiser and Bjornn 1979; Grost et al. 1991). Initially, Wolman pebble counts (Wolman 1954) were tested for characterizing study sites, however, pebble counts were not considered satisfactory for delineating the study sites. The best approach was a visual delineation of spawning patches based on the gravel characteristics of known spawning areas. Therefore, for this study, the portion of each potential spawning area with a dominant surficial particle size range 8–64 mm (b axis) was delineated visually to create each spawning patch polygon.

Gravel Composition

Only potential spawning sites with the percentage of surface fines less than approximately 40% were considered suitable for spawning (e.g., Bjornn and Reiser 1991) in the inventory phase of the project. For successful reproduction, spawning gravels must be sufficiently free of interstitial fine sediment to provide adequate exchange of oxygenated water to the embryos, removal of metabolic waste, and permit emergence of alevins.

Potential spawning sites with large imbricated cobble substrates, isolated boulders or high density dense woody vegetation (e.g., willows) that were arranged in such a way within the gravel patch to preclude fish from spawning were excluded from consideration.

Patch Dimensions

A minimum spawning patch size of 5 ft^2 was used as a cutoff for selecting gravel patches. In practice, most of the smaller size patches exhibited other undesirable conditions as identified above and only larger sites (e.g., 200^+ ft^2) ultimately were incorporated into the inventory.

Channel Location

Potential spawning patches that were higher than 6 ft above the base flow (approximately 1,200 cfs) were deemed to have limited spawning value (based on the historical hydrology review). Also, potential spawning patches that were on steep slopes (e.g., >30%) or that were located in slack water areas (areas without velocity at spawning flows) were excluded from consideration as potential spawning sites.

5.2.2. Physical Attributes

The physical attributes of the spawning patches were characterized by delineating spawning patch polygons, conducting patch elevation surveys, and by collecting bulk gravel samples.

Spawning Patch Polygons

The spatial extent of each potential gravel patch was mapped using a combination of field methods and GIS software. In the field, an initial series of patch widths were recorded at 6 foot intervals along a transect that followed the down-valley axis of each patch using a 150-foot open reel tape measure. This tape also provided a scale for photo documentation of the patch orientation and particle size. Each gravel patch perimeter was then delineated using a dense trace of GPS points using a Trimble GeoXT sub-meter accurate GPS unit. These GPS point traces were then uploaded into

GIS software (ESRI Arc 9) and overlain on top of high resolution aerial photography[1], providing a reference for accurately delineating the perimeter of each gravel patch and its relative position in the river channel. A polygon for each gravel patch perimeter was digitized using GIS software based on the GPS waypoint information, aerial photographic features, field maps, and measured transect distances. The resulting polygon layer was used to quantify the area of each polygon. The polygon layer was also used for subsequent field activities (surveying elevations, mapping depths and velocities) through the production of field maps that overlaid gravel patch polygon outlines on aerial photographs.

Patch Elevation Surveys

The relative elevation of each gravel patch was surveyed in order to tie all patches to stage-discharge relationships and facilitate the subsequent analysis of stage based suitable spawning area. Field crews conducted initial elevation surveys between September 22 and October 2, 2009. Two permanent elevation monuments were established along the riverbank in the vicinity of each patch. Monuments consisted of ¼" X ¾" rock anchor nails in large boulders, concrete footings, or bedrock outcroppings. All monuments were installed at elevations that would permit reoccupation at relatively high river stage. Elevation surveys were conducted using a Topcon automatic self-leveling laser mounted to a tripod at a central location where the entire patch was visible, including both monuments. All elevations were recorded to the nearest hundredth of a foot.

During elevation surveys, patch topography and variation in surface elevation was characterized by measuring the relative elevation at five locations on each gravel patch, including the upstream and downstream patch edge, river- and bank-ward edges, and the patch center. In addition, the water surface elevation was surveyed from a bearing approximately perpendicular to the patch long axis extending riverward from one of the monuments.

Bulk gravel sampling

Gravel composition at each patch was assessed via bulk gravel samples. Bulk gravel samples were taken using a standard number 2 round-point shovel, following methods outlined by Schuett-Hames et al. (1996). The majority of the gravel samples were collected in 2009 between September 29 and October 2, at or near base flow conditions, in order to minimize the need for in-water sampling.

Bulk samples were collected at random locations across each gravel patch. Between one and six individual samples per patch were collected, depending upon relative patch size. In total, 91 individual gravel samples were collected across all 58 potential spawning areas for subsequent analysis. During sampling, the locations of all bulk gravel sample sites were recorded using a handheld GPS unit.

[1] Digital aerial photography was obtained from the City of Spokane. The photographs had a pixel size of 0.5 feet.

Individual bulk samples were collected by working the shovel into the patch substrate perpendicular to the channel bed to a depth of between 6 and 8 inches. This sample depth corresponds to estimates and observations of rainbow trout egg pocket depth (DeVries 1997). Once at the desired depth, the shovel was gently rocked back to near parallel with the stream bed and the sample was removed and placed in a zip-lock bag. When samples were collected from inundated sites, a portable stilling well constructed of four ¼-inch aluminum foldable aluminum panels was used to reduce velocities around the sample site (Schuett-Hames et al. 1996). Although arguments have been presented for the inclusion of large or dominant particle sizes within bulk gravel samples (Kondolf 2000), samples that contained dominant clasts comprising an estimated 1% or more total sample weight were rejected, and a new sample was collected.

Each gravel sample was dried on small tarps (1 m^2) in the sun, and subsequently processed through a standard series of 9 sieves and into a pan (openings in mm: 0.25, 0.5, 1, 2, 4, 8, 16, 31.5, 63). All litter and extraneous materials were removed from the sample prior to determining the mass for each particle size class. The total mass (in grams) for each of the resulting 10 size categories (including the pan) was measured using a set of Pesola scales in order to calculate the mass fraction for each sieve class, a quantitative measure of gravel composition. Plots and tables displaying the gravel size composition using the combined bulk samples for each patch were developed.

Summarized literature data regarding fine sediment effects on spawning success (Kondolf 1993; 2000) were used to help rank the quality of spawning patches (Section 5.4.1). Gravels with approximately 22% or less fines (<1mm) prior to construction of redds have relatively high survivorship (emergence) (50% or greater) (Kondolf 1993, Kondolf 2000).

5.2.3. Hydrodynamic Attributes

Hydrodynamic attributes collected at each spawning patch included stage-discharge relationships and empirical maps (polygons) of spawning habitat depth and velocity over a wide range of flows.

Stage-Discharge Relationships

Water surface elevations were surveyed at each patch during five separate periods, spanning a wide range of river discharges. Survey methods followed the same protocol as described for the patch elevation surveys (see above). Discharge was obtained from the USGS Spokane River Gage. Water surface elevation was surveyed perpendicular to the center of the patch at a location on the same compass bearing as used during the initial patch elevation surveys. Water surface elevations were typically surveyed during the same field visits as the empirical depth and velocity mapping activities (Table 1; also see below).

Stage-discharge regressions were developed at each spawning patch. Regressions were based on the empirical water surface elevation (WSEL) data, discharge (Q) and the best fit stage-of-zero-flow (SZF):

$$WSEL = A\,(Q)^{B} + SZF \qquad (1)$$

where:

A and B = Empirical constants

Empirical Spawning Depth and Velocity Mapping

The portion of each spawning patch suitable for spawning/incubation relative to discharge was quantified by mapping suitable depths and velocities for spawning redband trout. The mapping was done at four different discharges spaced over a wide range (Table 1). Because the suitable depths and velocities for redband trout spawning in the Spokane River were unknown at the beginning of the work, literature data were used to develop depth and velocity categories (bins) for empirical mapping, Table 2 (Bovee 1978; Raleigh et al. 1984; EA Engineering 1987; TRPA unpublished data; TRPA 2002a; TRPA 2002b; WDFW 2004; Smith et al. 1987; TRPA 2004). The depth and velocity bins were later confirmed with empirical data from redband trout spawning observations in the Spokane River (see Section 5.3.2).

Empirical depth and velocity mapping at gravel patches consisted of drawing the wetted edge of the river and the boundaries between the different depth and velocity categories onto large scale field maps (aerial photographs) and recording a series of handheld GPS waypoints. On each visit, the depth and velocity category boundaries were identified through several iterative steps, beginning with an initial visual assessment of depth and velocity patterns over the entire patch. Then, a series of depth and velocity measurements were made across the patch to accurately identify boundaries between depth and velocity categories. Water velocity was measured at approximately six-tenths of the total depth using a Swoffer model 2100 current velocity meter and wading rod. Depth and velocity were recorded at the point of measurement directly onto the aerial photographs, facilitating the subsequent task of drawing suitable depth and velocity boundaries and assessing suitable spawning areas. Depth and velocity polygons were subsequently digitized from the aerial photos using GIS software, enabling the calculation of habitat areas for both depth and velocity. Each subsequent flow-based habitat mapping effort used a set of new field maps, which included the digitized depth and velocity polygons from the previous mapping effort for reference.

After the empirical mapping data were collected, a continuous relationship between spawning/incubation habitat area (see habitat categories in Table 2) and discharge was created for each patch between the discharges of 1,000 and 25,000 cfs. The relationship was created by plotting the spawning/incubation area measurements versus discharge and then developing a piecewise-linear relationship to interpolate/extrapolate the data.

5.3. Biological Spawning Characterization

The biological spawning characterization methods including spawning surveys, development of spawning habitat suitability criteria, and monitoring of artificial redds are discussed below.

5.3.1. Spawning Surveys

The period of peak redband trout spawning activity within the study reach has been previously documented to occur during mid to late April, with fry emerging sometime between late May and early June (Parametrix 2003). An initial set of spawning surveys was conducted during the first week of April in 2010 to determine the onset of redband trout spawning activity. Subsequent to this initial set of spawning surveys, three additional rounds of surveys were conducted between April 12 and April 27 to obtain a complete count of all observable redds within the study reach through the spawning period (Table 1).

During each round of spawning surveys, the entire study reach was assessed including all gravel patches identified previously as suitable and numerous inter-patch areas. Based on previous work, special attention was paid to areas with documented spawning, as well as bars and islands exhibiting willow growth and other areas of reduced velocity and potential gravel deposition (Parametrix 2003).

Several visual observation methods were used to accurately identify redds and spawning adult trout over gravel patches. Water clarity was excellent during all of the spawning surveys (visibility was approximately 10–15 ft). For gravel patches along accessible shoreline areas and in relatively shallow water, observation by either snorkeling or wading over the patch was used. For gravel patches in deeper water, observations were made from an open-frame cataraft and by snorkeling.

All redds were identified by visual observation and were counted only if there was a distinct area of disturbed, clean gravel characterized by a microtopography that included at least one definite pit and tailspill (Burner 1951). After each redd was visually observed and counted, its location was marked on a large-scale (1:628.2) aerial photograph. In addition, each redd location was recorded using a Garmin GPSmap 60CSx handheld GPS unit. In order to avoid repeat counts, each redd was marked with a gravel-filled biodegradable bag inscribed with the date, gravel patch ID, and redd number. Redd marker bags were then tied-off with biodegradable orange flagging and placed on the tailspill of each newly documented redd.

During spawning surveys, all shallow test digging was noted, but was not included in the total redd count. The presence of short “strings” or “chains” of redds that were likely constructed by the same fish were counted as a single redd unless multiple fish were observed on-site, or if excavated gravels were deposited over an existing tailspill or previously placed redd marker bag. The presence of all fish within the vicinity of each redd was noted on the field data sheets and a determination of the sex of each individual was made where possible.

Microhabitat characteristics, including depth and mean water column velocity, were measured for all newly constructed redds that were identified during each round of spawning surveys. Mean water column velocity (ft/s) was measured at 0.6 depth of the water column above each redd using a Swoffer model 2100 current velocity meter and wading rod. Depth and velocity measurements were collected at the upstream end of each redd pit.

Formal spawning surveys were concluded following the April 27 survey. No new redds or spawning fish were observed within the study reach during the May 4 hydrodynamic mapping surveys. A final survey of the study reach was conducted on May 11, following a period of unanticipated high flow, to note any redds that may have been constructed during the period of increased discharge.

5.3.2. Spawning Habitat Suitability Criteria

Redband trout spawning habitat suitability criteria for depth and mean column velocity were developed using the depths and velocities observed at the spawning redds in 2010. The frequency of observations in 0.5 ft depth and 0.5 ft/s velocity bins was plotted. Both the frequency and the percent of maximum frequency were plotted.

5.3.3. Artificial Redds

Survival to emergence of redband trout eggs within spawning gravel patches was assessed using modified Whitlock-Vibert (W-V) (Whitlock 1979) boxes and eyed triploid rainbow trout eggs. The spawning patches were visually categorized *a priori* into three potentially different quality strata (high, medium, and low) to test for differential survival of eggs. The quality strata were determined from the quality of the gravels (e.g., percent fines), the position of the patch in the channel (elevation, slack water, etc.), and experience of the biologists based on observations in previous salmonid spawning studies. Three spawning patches from each of the strata (nine patches total) were selected for monitoring (see Section 6.3.3). Three W-V boxes were installed in each of the selected patches (27 artificial redds in total). Four independent physical variables (fine sediment intruding into the W-V box, dissolved oxygen in the W-V box at two different times during incubation, water temperature, and dissolution rates of gypsum cylinders, a surrogate for intragravel flow rate) were monitored at the patches during the experiments.

The W-V redd boxes were populated with 50 eyed triploid rainbow trout eggs each, were installed April 21–22, 2010 and retrieved on May 17–18, 2010. Two water samples were taken from the boxes for field analysis of dissolved oxygen at 19 and 27 days following burial in the streambed. Gypsum cylinders (clod cards) of equal size (1.5 inches in diameter and 4 inches long) and weight were installed with each W-V box and retrieved 19–20 days post installation. These clod cards were dried and weighed to determine the mass loss during the period of deployment. Fine sediment that intruded into the W-V box gravels was dried and weighed. A temperature data logger (Onset Tidbit brand) was attached to one box in each patch to record intragravel temperatures.

Surface water temperatures were recorded upstream from the Spokane City wastewater treatment plant (data courtesy of City of Spokane).

Following retrieval of the W-V redd boxes (27 days after installation) counts of live alevins were used to determine the survival rate over the period of intragravel burial and compared for each of the artificial redds. The survival rates were then correlated with the physical parameters collected at the site. In addition to the assessment of survival, the live embryos at the end of the study were categorized into four developmental stages (i.e., fully absorbed yolk sac with complete ventral soft tissue suture, partially absorbed yolk with incomplete ventral suture - two grades, and hatchlings with little to no yolk sac absorption). This was done to capture any potentially sub-lethal effects of gravel patch quality on embryos. Details of the experimental methods are provided in Appendix A.

5.4. Effective Spawning And Incubation Habitat

Effective spawning and incubation habitat refers to the spawning habitat that remains continually suitable throughout the spring spawning and incubation period. The habitat must be suitable both for spawning during the spawning period and must remain suitable through the incubation period until alevins emerge from the gravels and into the river. Spawning habitat is that habitat provided during the spawning period. Incubation habitat is that habitat provided during the incubation period. Effective spawning and incubation habitat was quantified by ranking the spawning patches into quality strata and calculating effective habitat based on the beginning and ending river discharges, where the beginning discharge is the discharge during the spawning period and the ending discharge is the lowest discharge in the spawning and incubation period (see Section 6.3.1 for the spawning period).

5.4.1. Ranking of Spawning Patches

Spawning patches were ranked into quality strata based on non-flow related criteria. The criteria were as follows: whether or not trout spawning was observed at the site during the 2003 or 2010 spawning surveys, gravel quality, patch size, and patch location and local channel characteristics (see below). The ranking allowed effective spawning and incubation habitat to be calculated, for example, on all spawning patches combined and/or for only selected patches of similar non-flow related quality rankings. By separating the patch ranking from hydrology and hydraulics, the approach allowed hydrology and hydraulics to be assessed independently to determine which patches (of different non-flow quality) were suitable for spawning in different water year types or hydrology scenarios. The quality ranking was as follows:

- Rank 1a – High quality spawning patches with an area 250 ft^2 or greater and observed spawning (2003 or 2010).
- Rank 1b – High quality spawning patches with an area 250 ft^2 or greater and no observed limitations (e.g., excess fines), but no observed spawning during both years (and river discharges) when spawning was studied (2003 or 2010).

- Rank 2 – Medium quality spawning patches with one or more observed spawning limitations. Limitations included percentage of fines (<1mm) greater than 22% (potential low egg survival), small patch size (less than 250 ft^2), surficial gravel deposits (relatively thin gravel layer), and/or spawning patches with channel characteristics that likely result in low spawning quality (interspersed cobbles and boulders, steep slopes, excessive woody vegetation).

- Rank 3 – Low quality spawning patches with relatively severe spawning limitations related to the following: percentage of fines (<1mm) greater than 22% (potential low egg survival), small patch size (less than 250 ft^2), surficial gravel deposits (relatively thin gravel layer), and/or spawning patches with channel characteristics that likely result in low spawning quality (interspersed cobbles and boulders, steep slopes, excessive woody vegetation).

5.4.2. Effective Habitat

The spawning and incubation habitat area versus flow relationships developed for each spawning patch (Section 5.2.3) were used to calculate effective habitat for each patch and for all patches combined as follows. A matrix of beginning and ending flows was partitioned from 1,000 cfs to 25,000 cfs, in 1,000 cfs increments. The amount of spawning habitat (area and percent) that was suitable at the beginning flow was quantified for each patch and for all patches combined. The amount of that beginning spawning habitat that remained wetted at the ending flow was also quantified. The amount of the spawning habitat that remained wetted at the ending discharge (through incubation) was the effective habitat.

Tables of effective habitat were developed for all patches combined and for patches that had a rank quality of 1a, 1a–1b, 1–2, and 1–3. The tables were designed so the beginning discharge could be selected and then the amount and/or percent of habitat remaining at the ending discharge could be selected. An interactive Microsoft Excel spreadsheet tool was also developed so that the change in effective habitat with different beginning and ending discharges could be easily visualized.

6.0 RESULTS

6.1. HYDROLOGY REVIEW

Previous studies indicate that redband trout in the lower Spokane River typically spawn, incubate, and emerge from gravel redds between about the second week of April and then end of May and early June (Parametrix, 2003). The historical hydrology (1980–2010) shows that for spawning in April to be successful fish must spawn in hydraulically stable areas that will not scour or dewater until alevins emerge in early-June (Figure 2a). Hydrology in the Spokane River during the spawning and incubation period was highly variable between years and within years as measured at the USGS Spokane River Gage. The flows during the April spawning period (last three weeks in April; Section 6.3 below) ranged from approximately 5,000 to $25,000^+$ cfs and during the emergence period (e.g., first half of June), the flows ranged from about 2,000 to $25,000^+$

cfs (between year variability). The average, median, and 20% exceedance flows in April and June were similar; however, actual flows in individual years were typically much more variable (Figure 2a). Based on the flows during individual years, the difference between the spawning flow and the emergence flow (within year variability) ranged from a few cfs to greater than 15,000 cfs.

In 2010, flows during April spawning were relatively stable at approximately 6,000 cfs. Flows then increased to nearly 17,000 cfs in May with considerable variation in flows occurring (Figure 2b). Flows remained above the spawning flow through the incubation (early June) and throughout June. In early July (well after the emergence period), flows began dropping rapidly and reached 1,600 cfs by the end of the month. This hydrology is consistent with previous discussions that rapid changes in discharge are a normal and natural occurrence in the Spokane River (i.e., the river is naturally flashy) (Avista and Parametrix, 2004). For example, during spawning studies in 2003, Spokane River flow on April 19, 2003 was between 11,000 and 12,000 cfs then dropped to 5,850 cfs by May 29th (first observed emergence) and to 4,500 cfs by mid-June.

The majority of the flow fluctuation that occurs in the lower Spokane River is natural. The Upper Falls and Monroe Street HEDs are operated as run-of-river projects; meaning water flowing into the reservoirs is essentially equal to the water being discharged from the HEDs, and the reservoir water levels change little (FERC 2007). The Upper Falls and Monroe Street HEDs have very little storage (800 acre feet and 30 acre feet respectively) and are not operated as storage or power peaking projects. Therefore, the Upper Falls and Monroe Street HEDs have limited ability to manipulate discharge.

6.2. SPAWNING PATCH CHARACTERIZATION

The spawning patch characterization consisted of inventorying spawning patches, quantifying physical attributes, and quantifying hydrodynamic attributes.

6.2.1. Inventory

The spawning patch inventory identified 58 separate gravel patches in the 10 mile long study reach (Maps 2, 3 and 4; Table 3). The spawning patches were concentrated in the upper 4 miles of the reach (RM 69.7–73.7) with the largest concentration of spawning patches near the T.J. Meenach Bridge (RM 70) (primarily upstream of the bridge) (Map 3). Each spawning patch was assigned a unique identification number (Patch ID) that related to its specific location by river mile and left (L) or right (R) bank looking downstream (example patch 73.58L).

6.2.2. Physical Attributes

The physical attribute data for the spawning patches included spawning patch polygons, patch elevation surveys, and bulk gravel samples.

Spawning Patch Polygons

The spawning patches are shown in Maps 2–4 and can be seen in detail along with site photographs in the interactive electronic map in Appendix B (see electronic file). The spawning patch average size was 1,488 ft^2 (median of 638 ft^2) and the range was 208 ft^2 to 12,706 ft^2. Figure 3 shows the size distribution for the patches from upstream to downstream order (also see Table 3).

Patch Elevation Surveys

Patch elevations were combined with the stage-discharge relationships at each spawning patch (Section 6.2.3) to relate the elevations to discharge. Figure 3 shows the average, minimum, and maximum discharge elevation of all of the patches. Many of the patches are inundated over a wide range of discharges (i.e., various portions of the patch are inundated at different flows). The maximum range of patch inundation was approximately 18,000 cfs and the average range was about 4,600 cfs. Based on average elevation of the patches, the majority of the patches were cumulatively inundated by about 8,000 cfs (Figure 3).

Bulk Gravel Sampling

Fine sediment (<1 mm) concentration in the majority of the spawning patches was low enough to provide high survivorship for incubating eggs and emerging alevins (Figure 4; Table 3), typically less than the 22% of <1 mm fines prior to redd construction as identified by Kondolf (1993; 2000). The average percent of fines for all of the patches combined was 14.7%, while the maximum percentage was 39.4%. The average D50 particle size (median particle size of the bulk samples) of all the patches combined was relatively small, 11.7 mm (maximum 30.1 mm) (Figure 4; Table 3). Appendix C provides detailed substrate composition for all of the spawning patches.

6.2.3. Hydrodynamic Attributes

Hydrodynamic attributes collected at each spawning patch included stage-discharge relationships and empirical maps (polygons) of spawning habitat depth and velocity.

Stage-Discharge Relationships

Stage-discharge relationships (regressions) were developed for each spawning patch from 1,000 cfs to 25,000 cfs. The data used to create the relationships were based on empirical stage-discharge measurements over a range of flows from 1,280 to 16,500 cfs. Five stage-discharge data pairs were collected at all patches except one (70.28R), where four stage-discharge data pairs were collected. The stage-discharge relationships are continuous and can be used over a wider range of flows than 1,000 to 25,000 cfs, but they are most accurate in the 1,000 to 25,000 cfs range. The empirical data and plots of the stage-discharge regressions are shown in Appendix D. Table D1 shows the regression coefficients for each patch (see Equation 1, Section 5.2.3).

Empirical Spawning Depth and Velocity Mapping

The empirical depth and velocity mapping data were used to create piecewise-linear relationships of both spawning and incubation (wetted) habitat from 1,000 to 25,000 cfs (Appendix E). The empirical data used to create the relationships were based on four empirical mapping data sets collected within the following ranges of flow 2,980–3,810 cfs, 6,170–6,600 cfs, 8,320–10,200 cfs, and 11,140–16,500 cfs (Table 1). The data sets spanned the range of flows from 3,100 to 16,500 cfs. The relationships are continuous and represent an interpolation of the empirical data within the measured flow range (3,100 to 16,500 cfs) and an extrapolation of the data outside the measured flow range. The relationships are most accurate over the range of flows near the measured data (e.g., 2,000 to 20,000 cfs range) and less accurate the farther the extrapolations are from the measured data.

At two sites (69.87L and 70.39L), the empirical flow/habitat measurement at one flow appeared to be anomalous from the measurements at other flows. Likely this occurred either due to unique hydraulics at the flow (e.g., a log creating a flow deflection) or the way the field crew interpreted the habitat. At these two locations, the piecewise relationship did not use that data point (see Figures in Appendix E).

Spawning Habitat

A summary of the discharge range at which individual patches exhibit spawning habitat (Appendix E) is provided in Table 3. Three flow ranges were used, <11,000 cfs, 11,000 cfs–17,000 cfs, >17,000 cfs. These flow ranges were based on the average April flows (3rd week) (1980–2010) at three exceedance values, <33%, 33%–66%, and >66%, respectively.

Incubation Habitat

A summary is also provided in Table 3 of the discharge range, at which individual patches exhibit incubation habitat (Appendix E). The flow ranges are based on the same exceedance flow values used above (<33%, 33%–66%, and >66%), but for the 2nd week in June (1980–2010). The flow ranges are <5,000 cfs, 5,000 cfs–10,000 cfs, >10,000 cfs).

6.3. BIOLOGICAL SPAWNING CHARACTERIZATION

Biological spawning characterizations included spawning surveys, spawning habitat suitability criteria, and artificial redds.

6.3.1. Spawning Surveys

A total of 148 redband trout redds were observed during the 2010 spawning surveys. The first spawning was observed on April 7 (individuals and evidence of redd construction). The peak of the spawning occurred the third and fourth weeks in April 2010 (April 15 through 28) (Figure 5), with essentially all spawning completed by April 27. The flow during this period was approximately 6,000 cfs. During post-spawning verification in early May, five additional redds were located. These were created during a period of high flow, sometime between May 5 and May 10.

A total of 141 redds were documented at 12 of the 58 (21%) gravel patches within the study reach (Table 3; Maps 2, 5 and 6; Appendix B [see electronic file]). The majority of spawning (109 redds or 74%) in 2010 occurred at four primary sites:

- Riverbend Bar 68.35L (50 redds, 34% of total),
- Along the right bank immediately downstream of Sandifur Memorial Bridge 72.42R (27 redds, 18% of total),
- Along the left bank upstream of Sandifur Memorial Bridge 72.53L (11 redds, 7%).
- Along the right bank downstream of the Monroe Street HED 73.74R (21 redds, 14% of total), and

The other eight sites with redds contained from 2–6 redds (1–4%) of the spawning at each of the sites, or a total of 32 redds (Table 3; Maps 2, 5 and 6; Appendix B [see electronic file]). In addition, seven redds were observed at two off-patch locations: along the left-bank upstream of T.J. Meenach Bridge (RM 70.00) (three redds) and along the right bank at Upper San Soucci (RM 71.56) (four redds). The off-patch locations were in lower quality habitat than the inventoried patches. For example, RM 71.56 location had coarse surface gravels and the RM 70.00 location consisted of predominantly sand and small gravel substrate that had been deposited around the base of several willow trees.

The spawning patches where spawning occurred in 2010 were good spawning sites in the sense that they provided stable spawning and incubation habitat over a wide range of flows. The sites provided spawning habitat and incubation habitat from about 10,000 cfs down to 3,000 cfs or lower (Appendix B [see electronic file]). In 2010, the lowest flow during the incubation period was about 6,750 cfs (higher than the spawning flow) (Figure 2b); therefore, spawning sites that provided incubation over a wide range of flows were not required. However, if the hydrology would have been different, e.g., lower flows occurring at the end of the incubation period like occurs in many years, the spawning sites would have maintained good incubation conditions.

There were several spawning patches where spawning was observed historically in 2003 (Parametrix 2003), but few or no redds were observed in 2010. These sites include 70.13R, 71.52 right bank (not an inventoried patch), 73.10R, and 73.25L. In 2003 the flows during the spawning period were much higher (about 11,000–12,000 cfs) than in 2010 (~6,000 cfs). The spawning habitat analysis (Section 6.2.3) shows that these sites did not provide spawning habitat at 6,000 cfs (year 2010), but would have had good habitat at the higher flows, $11{,}000^{+}$ cfs, present in 2003. In addition, to the flow difference in 2003 versus 2010, at least one site appeared to have changed in physical nature since 2003. The 71.52 right bank location, documented with historical spawning in 2003, was given special attention in 2010, but the area was not classified/inventoried as a suitable spawning patch (contained coarse cobble and sand mix), nor was there spawning observed there. During the 2010 spawning period, the area was walked and snorkeled, but no fish/redds were observed.

6.3.2. Spawning Habitat Suitability Criteria

All spawning observed within the study reach (148 redds) occurred at depths ranging from 1.0–5.28 feet, with a mean depth of 3.51 feet and at velocities ranging from 0.5–3.5 ft/s, with a mean velocity of 1.9 ft/s. Figure 6 shows frequency plots and percent of maximum frequency plots of the depth and velocity utilization for redband trout in the Spokane River in 2010.

The majority of the velocity utilization occurred between about 0.5 and 3.0 ft/s, which is very close to the *a priori* velocity suitability categories used for the depth and velocity mapping (0.3–3.0 ft/s) (Table 3; Section 5.2.3). That is, the velocity utilization was similar to that observed in other studies (Smith 1973; Bovee 1978; Raleigh et al. 1984; EA Engineering 1987; TRPA unpublished data; TRPA 2002a; TRPA 2002b; WDFW 2004; Smith et al. 1987; TRPA 2004).

The spawning depth utilization (1.0–5.28 feet) in the Spokane River was deeper than has been typically observed in other studies for trout and salmonid spawning in general (Smith 1973; Bovee 1978; EA Engineering 1987; TRPA unpublished data; TRPA 2002a; TRPA 2002b; WDFW 2004; Smith et al. 1987; TRPA 2004), where depth utilization peaks are close to 1 foot deep and few redds are observed at depths greater than about 3 feet (Figure 6). Sometimes in other studies, during the development of spawning habitat suitability criteria, it has been assumed that deep water should remain suitable, even though no spawning observations exist in deep water (e.g., Smith et al. 1987) or because there was some limited documentation of deep water spawning (e.g., Orcutt et al. 1968). In one report where suitability criteria were developed for rainbow trout using a variety of data sets, Raleigh (et al. 1984)[2], deep water spawning suitability for rainbow trout was based on a single study (Hartman and Galbraith 1970) that documented the relatively deep water spawning habitat of the largest rainbow trout in the world (Gerrad rainbow trout).

The *a priori* depth categories used for mapping spawning habitat in this study were 0.0–<0.3, 0.3–2.5, and >2.5 feet. Both of the two deeper water categories were assumed to represent suitable spawning conditions; however, this was originally based on the concept that 0.3–2.5 feet was the typical depth at which rainbow trout would spawn and that fish might also be observed in water deeper than 2.5 feet. The *a priori* category was "wrong" for deep water in the sense that a very large portion of the spawning in the Spokane River in 2010 occurred in depths greater than 2.5 feet, outside of the assumed 0.3–2.5 feet category. The deep water mapping category >2.5 feet, however, picked up this deep water spawning and the empirical spawning habitat mapping results are

[2] Raleigh et al. 1984 assumed relatively deep water was suitable for rainbow trout based on data in Hartman and Galbraith (1970) for Gerrard rainbow trout, the largest rainbow trout in the world (e.g., average about 17^{+} lbs).

consistent with the “approach” that deep water does not limit trout spawning. That is, deep water is suitable for spawning.

6.3.3. Artificial Redds

The artificial redd results included the survival and developmental stage of eggs/alevins and the physical variables measured at the redds during the 26 day installation period.

Survival and Developmental Stage

The assessment of intragravel conditions on embryo survival suggests that the inventoried spawning patch habitat (i.e. the intragravel environment) was functional and exerted limited effect on incubating embryos. Counts of live alevins from the W-V boxes indicated that survival rates over the period of intragravel assessment averaged 88% (Table 4). The lowest survival in a W-V box was 64% and the highest was 98%.

The high survival for the artificial redds across all sites means that the physical conditions at the redds, including the variables that were measured (fine sediment intrusion, clod card dissolution, dissolved oxygen, temperature) were suitable for alevin development. As a result, the relationships between survival and the measured independent variables was weak (Figures 7–10). The relationships are, however, generally in the direction that would be expected. For example the relationship with fine sediment that intruded into the W-V boxes in Figure 7 was weakly negative and likewise the relationship between clod card dissolution, a surrogate for intragravel flow rates, and survival was weakly positive (Figure 8). The trend with dissolved oxygen was weakly positive at Time 1 and virtually flat at Time 2 (Figure 9). There was a weakly positive survival trend with average temperature (Figure 10).

Developmental stage of embryos was similar for all samples except for W-V Unit #3 at patch 70.65R (Table 4), which had the highest amount of fine sediment intrusion, the lowest mass loss of its associated clod card and low dissolved oxygen at both measurement times (Table 4). Forty of the 41 live alevins at unit #3 had little absorption of their yolk. While this unit exhibited only slightly less than average survival, the developmental state of the alevins was significantly less advanced in comparison to every other unit. The fact that we detected values of explanatory variables out of range with the rest of the units and that they had a measureable, yet sub-lethal effect on incubating alevins, suggests that the methods we used to assess survival and developmental stage were sensitive to intragravel conditions within the streambed and that over the broad distribution of the inventoried sites sampled in the river, gravel conditions in the Spokane River were favorable for incubating salmonid embryos.

Physical Variables

At the time of installation of the W-V boxes water depths ranged from 2.5 to 0.6 feet (average 1.1 foot deep) and velocities of 2.54 to 0.12 feet per second (average 1.0 foot per second) (Table 4). The depths and velocities over the patch and the boxes varied over the deployment period as stage and flow fluctuated in the river. Mass loss of the clod cards ranged from 3–100% with an average of 52.5%. Fine sediment intrusion into the WV-boxes ranged from 90.0–1.0 grams, average 30.9 grams. Dissolved oxygen at Time 1 ranged from 3.8 to 14.0 mg/l and average 8.8 mg/l and at Time 2 ranged from 4.0–10.0 mg/l with an average of 8.3 mg/l. Dissolved oxygen readings were 77% of surface water values on average.

Average temperature from the W-V boxes indicated a small range of variability 49.2 to 52.9 F (average 50.8 F); however, there was a high degree of variability in the temporal pattern of temperature (Figure 10). There were three distinct patterns of temperature fluctuation (Figure 11). Four of the sites appeared to track the surface water temperature closely, suggesting coupling of the intragravel environment and exchange with the river. A second group represented by two sites, showed stable temperatures influenced by groundwater sources near the active channel. Both of these sites were on the right bank in the vicinity of T.J. Meenach Springs. Temperature at one of these sites (70.13R) was depressed as stage increased on May 4, suggesting a flow induced coupling with surface water while the other site remained stable. The third group of two sites displayed temperature fluctuations intermediate to the ground water controlled group and the surface water controlled group. This third group showed a stabilizing trend with ascending temperatures in May and a mildly fluctuating diurnal pattern within the range of the groundwater controlled group at the time of retrieval (Figure 11).

6.4. Effective Spawning And Incubation Habitat

Characterization of effective habitat included both ranking of spawning patches and quantification of effective habitat.

6.4.1. Ranking of Spawning Patches

The non-flow related quality rank of each spawning patch is shown in Table 3. A total of 12 patches were ranked 1a and 21 patches were ranked 1b. The patches with a rank of 1a or 1b are high quality patches with no non-flow related spawning limitations. Rank 1b sites are sites that have been differentiated from 1a sites because spawning was not observed (confirmed) at these patches in the two years (2003 or 2010) that spawning was studied in the river. The rank 2 and 3 spawning patches are medium and low quality sites, respectively, with non-flow related deficiencies that are outlined in Table 3. These patches may be suitable spawning patches based on most of the physical conditions, but they are lower quality spawning patches than the rank 1 sites.

6.4.2. Effective Habitat

The effective habitat analysis included spawning habitat versus flow relationships and calculation of effective spawning and incubation habitat.

Spawning Habitat Versus Flow Relationships

Detailed spawning and incubation habitat versus discharge relationships for each of the individual spawning patches were presented in Section 6.2.3. The cumulative amount of spawning habitat versus flow for four different groupings of spawning patches (rank 1a, ranks 1a and 1b, ranks 1–2, and ranks 2–3) are shown here in Figures 12, 13, 14 and 15, respectively. The amount of spawning habitat for all four groupings increased steadily with increasing discharge from low flow up to approximately 11,000 cfs and then generally leveled off. Based on historical hydrology, 66% of the time discharge during April (3rd week) is greater than 11,000 cfs and provides approximately maximum spawning habitat. Even when spawning flows are as low as 6,000 cfs, which occurs less than 20% of the time (Figure 2a), approximately 50% of the maximum spawning habitat in the study reach is available (Figures 12–15).

Approximately 67% of the total spawning habitat available in the study area is provided by patches with rank 1a, 90% for patches with rank 1a–1b, and 96% for patches with rank 1–2. Very little habitat is provided by the patches with rank 2 or 3 (6% and 4%, respectively).

Effective Spawning and Incubation Habitat

Effective spawning and incubation habitat matrices are shown for each of the four groupings of patch quality (rank 1a, ranks 1a and 1b, ranks 1–2, and ranks 2–3) in Tables 5, 6, 7, and 8, respectively. The effective spawning and incubation tables provide a tool to assess and/or manage effective spawning and incubation habitat. The effective spawning and incubation tables are used by looking up the flow that existed in the river at the time of spawning (e.g., median average daily flow during the 3rd week of April) and then looking up the habitat that would remain effective through the incubation period based on the lowest average daily flow during the incubation period (late April to early June). Figure 16 shows a graphical version of the tables for initial spawning discharges of 15,000 cfs and 6,000 cfs for patches ranked 1–3.

Two examples of using the effective habitat tables are provided below:

- During the 2010 spawning period (April 15 through April 21), flow in the Spokane River was approximately 6,000 cfs (Figure 2). For the 1a and 1b ranked sites (Table 6), where the majority of the habitat exists, the initial amount of spawning habitat was 22,000 ft^2, and because the flow never went below 6,000 cfs the through the incubation period in early June (Figure 2), the total effective spawning and incubation habitat was 22,000 ft^2 (Table 6a). If, however, the flow had dropped to 4,000 cfs during the incubation period, then 18,000 ft^2, or 81% of the habitat would have remained as effective spawning and incubation habitat (Table 6).

- During spawning studies in 2003, Spokane River flow during April spawning was approximately 11,500 cfs. Flows then dropped to 5,850 cfs by May 29th (first observed emergence) (Parametrix 2003) and to approximately 4,500 cfs by mid-June. By interpolating the 11,000 and 12,000 cfs spawning habitat flow in Table 6 and the ending incubation habitat flow results in the table, approximately 70% of the spawning habitat remained effective through the end of May and 58% of the spawning habitat would have remained effective through mid-June.

The percent of the initial spawning habitat that would remain effective is generally similar for each of the quality groupings of patches (Tables 5, 6, 7, and 8) even though the total amount of effective habitat is different. Using Table 6 (for patches with rank 1a and 1b) incorporates 90% of the total habitat and provides results similar to those obtained using one of the other groupings of spawning patches. For example, using the analysis described above (6,000 cfs spawning flow goes to 4,000 cfs incubation flow), the percent of effective spawning and incubation habitat remaining is 81% using Table 6 (rank 1 patches) and 82% based on using Table 7 (rank 1–2 patches).

7.0 SUMMARY

Lower Spokane River hydrology during the redband trout spawning and incubation period (April–June) was highly variable within years (range between spawning and incubation as high as 15,000 cfs) and between years (5,000 cfs to $25,000^{+}$ cfs spawning flows in April).

A total of 58 spawning patches were identified and inventoried in the lower Spokane River study area (10 miles). Most of the spawning patches were in the upper 4 miles of the study reach. The largest concentration of spawning patches was in the T.J. Meenach Bridge area.

Most spawning patches were watered over a wide range of discharges (e.g., average patch range was 4,600 cfs) (i.e., the individual patches consisted of a range of channel elevations). The average discharge at which the majority of the patches/patch areas were inundated was approximately 8,000 cfs.

The fine sediment content of the inventoried spawning patches was generally within the range that provides successful spawning (average 14.7% fine sediment <1 mm).

Stage-discharge relationships and empirical depth/velocity habitat mapping provided hydrodynamic attributes over a wide range of discharges 1,000 cfs to 25,000 cfs. This allowed spawning and incubation habitat to be quantified over a wide range of discharges (1,000 cfs–25,000 cfs).

A total of 148 redband trout redds were located during the spawning season in 2010. The majority of the spawning occurred during the last two weeks of April, between April 15 and April 27. This spawning period timing is consistent with the April 10 to April 22 period observed during studies in 2003 (Parametrix 2003). A total of 130 redband trout redds were identified during the spawning season in 2003. Fry emergence was first observed on May 29 in 2003 (Parametrix 2003). In this report, we assume emergence occurs during the end of May and early June. The water depth of spawning habitat utilized by redband trout in the lower Spokane River was unique. Fish spawned in deep water habitat compared to other studies of salmonid spawning. The average depth of spawning was 3.51 feet and redds were observed at water depths of 5.3 feet. This may be a biological mechanism to protect redds against dewatering during incubation due to the natural highly variable flows (between and within years) that occur in the Spokane River.

Artificial redds installed in spawning patches with a range of different quality rankings showed that intragravel survival was high (average 88%) in all of the patches. Generally, therefore, the inventoried patches provide good egg survival habitat.

Patch spawning quality was ranked high (rank 1), medium (rank 2), and low (rank 3) based on non-flow related attributes. The rankings were used to identify the most important spawning patches and to allow grouping of patches for effective spawning and incubation habitat analyses. Rank 1 sites (1a and 1b) provided the majority, approximately 90%, of the spawning habitat in the 58 surveyed patches. Very little additional habitat was provided by the rank 2 (6%) and rank 3 (4%) sites.

The spawning habitat versus discharge relationship for all of the different quality groupings of spawning patches peaked at approximately 11,000 cfs. At flows higher than 11,000 cfs there was little change in the total amount of spawning habitat versus flow relationship. At lower flows the amount of habitat was lower (spawning habitat was positively related to discharge). At lower flows, a relatively high percentage of the spawning habitat is available. For example, at 6,000 cfs, 50% of the total spawning habitat is still available.

Effective spawning and incubation habitat is the habitat that remains continually suitable throughout the spring spawning and incubation period. Effective spawning and incubation habitat was quantified in 1,000 cfs increment tables of initial spawning discharge (1,000 to 25,000 cfs) and minimum flow during the incubation period (1,000 to 25,000 cfs). These tables provide an easy to use tool for assessing and/or managing effective spawning and incubation habitat. The tables are used by looking up the amount of habitat that was available at the spawning discharge (third week of April) and then using the lowest flow occurring during the incubation period (for example, through the first week of June) to determine the amount or percent of habitat that remained effective.

In 2010, flows during April spawning were relatively stable at approximately 6,000 cfs. Flows throughout the incubation period remained above the spawning flow and 100% of the spawning habitat remained effective through the incubation period (flow did not drop below 6,000 until July). During spawning studies in 2003, Spokane River flow during spawning in April was approximately 11,500 cfs then dropped to 5,850 cfs by May 29th (first observed emergence) and approximately 4,500 cfs by mid-June. Approximately, 70% of the spawning habitat remained as effective spawning and incubation habitat through the end of May and 58% through mid-June in 2003.

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TABLES

Table 1. Timing of Data Collection.

Sampling Period	Discharge Range (cfs)	Data Collected											
		Identification of Potential Spawning Sites	Initial Gravel Patch Inventory/Patch Boundary Mapping	Gravel Patch Elevation Surveys	Shore-line Mapping	Bulk Gravel Samples	Stage-Q	Depth & Velocity Polygons	Pre- and Post-spawning period verification	Spawning Surveys Redd Counts	W-V Box & Clod Card Installation	Clod Card Retrieval & First DO	W-V Box Retrieval & Last DO
Sept. 8-10, 2009	758 - 1360	X											
Sept. 16-19, 2009	1020 - 2890		X										
Sept. 22-29, 2009	1140 - 1540			X			X						
Sept. 29-Oct. 02, 2009	945 - 2270			X		X							
Oct. 7-8, 2009	1340 - 1590				X								
Dec. 15-18, 2009	2980 - 3810						X	X					
April 5-8, 2010	6170 - 6600						X	X	X	X			
April 12-13, 2010	5020 - 6880									X			
April 20-22, 2010	5740 - 6270									X	X		
April 26-27, 2010	6250 - 6780									X			
May 4-7, 2010	11400 - 16500						X	X	X				
May 10-13, 2010	8320 - 10200						X	X	X			X	
May 17-18, 2010	8090 - 10600												X
Oct. 20, 2010	2040 - 2200					X							

Table 2. Empirical Spawning and Incubation Habitat Mapping Depth and Velocity Bins.

Depth/Velocity Bins	Suitable for Spawning	Suitable for Incubation
Depth (ft)		
0.0–<0.3	No	Yes[1]
0.3–2.5	Yes	Yes
>2.5	Yes	Yes
Velocity (ft/s)		
0.0–<0.3	No	Yes[1]
0.3–3.0	Yes	Yes
>3.0	No	Yes

[1]Only if the depth is greater than 0.0 ft and velocity is greater than 0.0 ft/s.

Table 3. Spawning Patch Details.

Spawning Patch ID (River Mile and Bank)	Site Location	Patch Number	Site Rank	Reasons for Site Rank Less Than 1	Area (sq. ft.)	% < 1 mm fines	D50	Number of Observed Redds		Spawning Habitat Flow Range (cfs)[1]			Incubation Habitat Flow Range (cfs)[1]		
								2010	2003	< 11,000	11,000 - 17,000	> 17,000	< 5,000	5,000 - 10,000	> 10,000
Monroe Street Bridge															
73.74R		58	1a		#######	6	####	21		X	*		X	X	X
73.63R		57	1a		6586	13	####	3		X	X	X	X	X	X
73.58L		56	1a		1069	7	####	3		X	X	X	X	X	X
73.54R		55	2	Steep slope, surficial gravel, mixed with cobble/boulder	1691	13	####			*	X	X	*	X	X
73.49L		54	3	Steep slope, surficial gravel, mixed with cobble/boulder, small size	214	16	####			*	X	X		X	X
Maple Street Bridge															
73.43L	Peaceful Valley	53	3	Surficial gravel, mixed with cobble/boulder, small size	230	18	9			*	X	X	X	X	X
73.25L		52	1a		9403	17	4		18	X	X	X	X	X	X
73.18R		51	1b		1393	16	####			X	X	X	X	X	X
--		--	--		--	--	--		27	--	--	--			
72.73L		50	3	Steep slope, surficial gravel, high % fines	334	32	####			*	X	X	*	X	X
72.71L		49	3	Steep slope	602	19	####			*	X	X		X	X
72.67L		48	2	High % fines	661	32	####			*	X	X		X	X
72.56L		47	3	Surficial gravel, high % fines	547	39	2			*	X	X	*	X	X
72.53L		46	1a		700	16	7	11		X	X	X	X	X	X
Sandifur Memorial Bridge															
72.47L		45	2	Small size	212	2	6			X	*		X	X	X
72.42R		44	1a		3744	0	####	27		X	X		X	X	X
72.24R		43	2	High % fines	960	27	####			X	X	X	*	X	X
Hangman (Latah) Creek															
72.19R		42	1b		1883	5	####			X	X	X	X	X	X
71.74L		41	1b		288	3	####			*	*			X	X
71.71L		40	1b		474	4	####			*	X	X		X	X
71.69L		39	1b		1068	6	####			X	X	X	*	X	X
71.66L		38	2	Large substrate	304	9	####			X	X	X	*	X	X
--	Upper San Souci	--	--		--	--	--	4		--	--	--			
71.52R		37	1a		2130	19	6		11	*	X	X		X	X
71.3L		36	1b		2441	9	9				*	*			X
71.26L		35	1b		1765	14	5				X	X		*	X
71.23L		34	1b		264	5	####			*	X	X		X	X
70.88R	San Souci	33	2	mixed with cobble/boulder, woody vegetation, narrow	572	15	7				X	X			X
70.83R		32	2	High % fines, woody vegetation	339	25	4		1[2]		X	X		*	X
70.77R		31	1b		1206	11	####			X	X	X	*	X	X
70.65R	Lower San Souci	30	2	Located in back eddie	402	17	7			X	X	X	X	X	X
70.39L		29	1b		421	16	6			X	X		X	X	X
70.35L		28	1b		622	12	####			X	*		*	X	X
70.28R		27	3	Steep slope, surficial gravel, mixed with cobble/boulder	359	15	####			*	X	X	*	X	X
70.27L		26	1b		355	12	####			*	X	X		X	X
70.26R		25	3	Steep slope, surficial gravel, mixed with cobble/boulder	290	7	####			*	X	X		X	X
70.25L		24	1a		646	11	####	5		X	X	*	*	X	X
70.2L		23	1a		1617	12	####	4		X	X	X	X	X	X
70.18R		22	3	mixed with cobble/boulder, small size	208	11	####				X	X		*	X
70.17L		21	1b		340	21	8				X	X		X	X
70.14L		20	2	High % fines, mixed with cobble/boulder	542	25	5			*	*			X	X
T.J. Meenach Springs															
70.13R		19	1a		2000	12	####	2	52	X	X	X	*	X	X
70.06L		18	1b		1306	15	8					X[3]	X	X	X
70.04R		17	1a		1068	16	####	3		X	X	X	X	X	X
70.03L		16	1b		1624	19	####					X[3]	X	X	X
--		--	--		--	--	--	3		--	--	--			
69.96L		15	2	Large substrate, small size	214	3	####			X			X	X	X
69.96R		14	1b		1076	13	6			X	X	X	*	X	X
69.92L		13	1b		1688	20	7			X	X		*	X	X
69.92R		12	1b		415	20	7					X[3]	*	X	X
69.91L		11	1b		292	11	8				X	X		X	X
69.89L		10	1b		346	8	####			*			X	X	X
69.87L		9	1a		269	17	####	6		X	X	X	X	X	X
T.J. Meenach Bridge															
69.79R		8	3	Steep slope, high % fines	630	24	5			*	X	X		X	X
69.77R	Downriver Road	7	1a		965	12	8	6		X	X	X	X	X	X
69.72R		6	1b		1973	10	####			X	X	X	*	X	X
68.35L		5	1a		9821	22	5	50	21	X	X	X	X	X	X
68.34L		4	1b		1023	13	####				X	X		*	X
67.78L		3	2	Large substrate, mixed with cobble/boulder	599	9	####			*			X	X	X
Treatment Plant															
Bowl and Pitcher Park															
Swinging Bridge															
65.39R		2	3	Steep slope, surficial gravel, high % fines, boulder	1126	23	####					X[4]	*	X	X
65.38R		1	3	Steep slope, high % fines	267	32	####					X[4]		*	X

[1]Spawning habitat throughout this flow range (X) and spawning habitat occurs in a portion of this flow range (*).
[2]Redd observed in the San Souci Area. No detailed coordinates were available.
[3]No flow or spawning habitat in this side channel at flows < 15,000 cfs. At higher flow the spawning patch would become usable.
[4]No spawning habitat observed at flow < 15,000 cfs. At higher flows this spawning patch is likely not usable.

Table 4. Artificial Redd Summary Data.

				Egg Survival Data						Physical Habitat Data							
				Yolk Sac										Dissolved Oxygen (mg/l)			
WV Box Number	Spawning Patch ID	Installation Date and Time	Retrieval Date and Time	Full	Partially Absorbed	Absorbed	Deceased Fish	Live Fish	Percent Survival	Intruded Sediment Weight (g)	Percent Clod Card Dissolution	Water Depth at Installation (ft)	Water Velocity at Installation (ft/sec)	Day 18	Day 27	Average Redd Temperature (^oF)	A Priori Quality Strata
1	70.65R	4/21/2010 19:00	5/19/10 11:04	0	7	40	0	47	94%	25.5	9%	2.4	2.54	11	7	49.2	Medium
		4/21/2010 19:10	5/19/10 10:40	0	5	27	13	32	64%	35.9	7%	2	1.7	10	9		Medium
		4/21/2010 19:18	5/19/10 10:20	0	40	1	5	41	82%	90.0	3%	2.4	1.4	3.8	4		Medium
2	70.77R	4/22/2010 8:59	5/18/10 16:48	0	7	40	4	47	94%	12.0	58%	1.1	0.6	10	9	49.5	Medium
		4/22/2010 9:06	5/18/10 16:48	0	0	43	3	43	86%	6.9	31%	1.3	1.17	10	9		Medium
		4/22/2010 9:08	5/18/10 17:11	0	1	47	5	48	96%	35.9	41%	1.1	0.41	9	8		Medium
3	72.56L	4/22/2010 10:34	*Box missing, vandalized*													--	Low
		4/22/2010 10:37	5/18/10 10:34	0	2	43	5	45	90%	37.3	95%	0.8	1.23	10	7		Low
		4/22/2010 10:41	5/18/10 10:34	0	2	42	1	44	88%	40.9	74%	1	1.08	11	8		Low
4	71.91R	4/22/2010 11:42	5/19/10 7:48	0	0	47	3	47	94%	9.3	35%	1.1	1.1	11	9	49.3	High
		4/22/2010 11:43	5/19/10 7:48	0	1	41	8	42	84%	9.5	15%	0.8	1.85	11	9		High
		4/22/2010 11:38	5/19/10 7:48	0	1	46	3	47	94%	1.0	70%	1	2.54	14	10		High
5	70.25L	4/22/2010 14:58	5/18/10 11:40	0	1	44	0	45	90%	29.6	24%	1	1.54	7	10	50.8	High
		4/22/2010 15:01	5/18/10 12:07	0	2	45	3	47	94%	32.9	63%	0.7	1.91	6	6		High
		4/22/2010 15:04	5/18/10 12:20	0	1	41	2	42	84%	22.7	40%	0.7	0.6	7	7		High
6	70.13R	4/22/2010 13:39	5/18/10 13:56	0	0	49	1	49	98%	16.8	47%	1	0.3	8	8	52.9	Medium
		4/22/2010 13:42	5/18/10 14:10	0	0	49	0	49	98%	19.4	100%	0.8	0.31	8	8		Medium
		4/22/2010 13:46	5/18/10 14:26	0	0	47	1	47	94%	18.2	100%	1	0.49	7	9		Medium
7	69.77R	4/22/2010 17:24	5/18/10 13:19	0	0	45	6	45	90%	15.7	58%	1.5	0.86	7	9	51.1	High
		4/22/2010 17:14	5/18/10 13:08	0	4	8	4	--[1]		17.7	57%	1	1.06	11	11		High
		4/22/2010 17:19	5/18/10 12:54	0	0	39	6	39	78%	23.2	11%	1.1	0.91	7	9		High
8	69.92R	4/22/2010 18:25	5/18/10 14:50	0	0	41	4	41	82%	82.6	100%	1.1	0.31	8	8	52.5	Low
		4/22/2010 18:17	5/18/10 14:50	0	0	45	2	45	90%	38.8	66%	1	0.22	7	8		Low
		4/22/2010 18:21	5/18/10 15:11	0	1	34	15	35	70%	71.7	100%	1	0.23	8	8		Low
9	73.49L	4/22/2010 19:29	5/18/10 9:04	0	3	41	8	44	88%	53.5	70%	0.6	0.22	9	7	49.3	Low
		4/22/2010 19:25	5/18/10 9:04	0	2	36	11	38	76%	27.2	47%	0.8	0.12	8	9		Low
		4/22/2010 19:34	5/18/10 9:04	0	5	41	6	46	92%	28.2	47%	0.6	1.28	9	9		Low
10	Control	4/23/2010 9:05	5/17/10 14:50	0	0	42	0	42	84%	59.8	*Cards lost*	0.4	2	7	10	52.4	Cntrl
		4/23/2010 9:00	5/17/10 14:50	0	0	48	0	48	96%	49.1	*Cards lost*	0.5	0.6	8	6		Cntrl
		4/23/2010 8:50	5/17/10 14:50	0	0	50	0	50	100%	22.0	63%	0.5	0.97	7	10		Cntrl

[1]Box chewed by otter.

Table 5. Effective Spawning and Incubation Habitat Amount (ft2/1000 ft) (top) and Percent (bottom) in Spawning Patches Ranked 1a.

Spawning Discharge	Ending Incubation Discharge (cfs)																									Total
(cfs)	25000	24000	23000	22000	21000	20000	19000	18000	17000	16000	15000	14000	13000	12000	11000	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000	(ft^2)
25000 cfs	30	30	30	30	30	30	30	30	30	30	30	30	30	29	29	29	28	27	26	24	22	20	18	16	15	30.0
24000 cfs		30	30	30	30	30	30	30	30	30	30	30	30	30	29	29	28	27	26	24	22	20	18	16	15	30.1
23000 cfs			30	30	30	30	30	30	30	30	30	30	30	30	29	29	28	27	26	24	22	20	18	16	15	30.1
22000 cfs				30	30	30	30	30	30	30	30	30	30	30	29	29	28	27	26	25	22	20	18	16	15	30.2
21000 cfs					30	30	30	30	30	30	30	30	30	30	30	29	29	27	26	25	22	20	18	16	15	30.3
20000 cfs						30	30	30	30	30	30	30	30	30	30	29	29	28	26	25	22	20	18	16	15	30.3
19000 cfs							30	30	30	30	30	30	30	30	30	29	29	28	26	25	22	20	18	16	15	30.4
18000 cfs								30	30	30	30	30	30	30	30	29	29	28	26	25	22	20	18	16	15	30.4
17000 cfs									30	30	30	30	30	30	30	30	29	28	27	25	23	20	18	16	15	30.4
16000 cfs										31	31	30	30	30	30	30	29	28	27	25	23	20	18	16	15	30.6
15000 cfs											31	31	31	31	30	30	29	28	27	25	23	21	18	17	15	30.8
14000 cfs												30	30	30	30	29	29	28	26	25	22	20	18	16	15	30.1
13000 cfs													31	31	31	31	30	28	27	25	22	20	18	16	14	31.2
12000 cfs														32	32	32	31	29	27	25	22	20	17	15	14	32.4
11000 cfs															32	32	30	28	26	24	21	19	16	14	13	32.0
10000 cfs																31	29	27	25	22	20	18	15	13	11	30.6
9000 cfs																	27	25	23	21	19	16	14	12	11	26.8
8000 cfs																		23	21	19	17	16	14	12	10	23.1
7000 cfs																			19	18	16	15	13	12	10	19.4
6000 cfs																				17	16	14	13	12	10	16.8
5000 cfs																					16	15	13	12	10	16.0
4000 cfs																						15	14	12	10	15.2
3000 cfs																							14	12	11	14.1
2000 cfs																								12	10	12.3
1000 cfs																									11	10.8

Spawning Discharge	Ending Incubation Discharge (cfs)																								
(cfs)	25000	24000	23000	22000	21000	20000	19000	18000	17000	16000	15000	14000	13000	12000	11000	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000
25000 cfs	100	100	100	100	100	100	100	100	100	99	99	99	99	98	98	97	94	91	87	81	74	66	59	53	48
24000 cfs		100	100	100	100	100	100	100	100	99	99	99	99	98	98	97	94	91	87	81	74	66	59	53	48
23000 cfs			100	100	100	100	100	100	100	99	99	99	99	98	98	97	94	91	87	81	74	66	59	53	48
22000 cfs				100	100	100	100	100	100	99	99	99	99	98	98	97	94	91	87	81	74	66	59	53	48
21000 cfs					100	100	100	100	100	99	99	99	99	98	98	97	94	91	87	81	74	66	59	53	49
20000 cfs						100	100	100	100	99	99	99	99	98	98	97	94	91	87	81	74	66	59	53	49
19000 cfs							100	100	100	100	99	99	99	98	98	97	94	91	87	82	74	66	59	53	49
18000 cfs								100	100	100	100	99	99	98	98	97	95	91	87	82	74	66	59	53	49
17000 cfs									100	100	100	99	99	99	98	97	95	91	87	82	74	66	59	53	49
16000 cfs										100	100	99	99	99	98	97	95	91	88	82	74	67	59	53	49
15000 cfs											100	100	99	99	98	98	95	92	88	82	75	67	60	54	50
14000 cfs												100	100	99	99	98	95	92	88	82	74	67	59	53	49
13000 cfs													100	100	99	98	95	91	86	80	72	64	57	50	46
12000 cfs														100	99	98	94	89	84	78	69	61	54	47	42
11000 cfs															100	99	94	88	82	75	67	59	52	45	39
10000 cfs																100	94	88	80	73	65	58	50	43	38
9000 cfs																	100	93	85	77	69	61	53	45	39
8000 cfs																		100	92	84	75	67	59	50	44
7000 cfs																			100	92	84	77	69	59	52
6000 cfs																				100	93	86	78	69	60
5000 cfs																					100	92	84	73	64
4000 cfs																						100	91	79	69
3000 cfs																							100	88	75
2000 cfs																								100	85
1000 cfs																									100

Table 6. Effective Spawning and Incubation Habitat Amount (ft2/1000 ft) (top) and Percent (bottom) in Spawning Patches Ranked 1a - 1b.

Spawning Discharge (cfs)	Ending Incubation Discharge (cfs)																									Total
	25000	24000	23000	22000	21000	20000	19000	18000	17000	16000	15000	14000	13000	12000	11000	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000	(ft^2)
25000 cfs	41	41	41	41	41	41	41	41	41	41	41	40	39	39	38	37	36	34	31	29	25	22	19	16	15	41.1
24000 cfs		41	41	41	41	41	41	41	41	41	41	40	39	39	38	37	36	34	31	29	25	22	19	16	15	41.2
23000 cfs			41	41	41	41	41	41	41	41	41	40	40	39	38	37	36	34	31	29	25	22	19	17	15	41.4
22000 cfs				41	41	41	41	41	41	41	41	40	40	39	38	37	36	34	32	29	26	22	19	17	15	41.5
21000 cfs					42	42	42	42	41	41	41	41	40	39	38	37	36	34	32	29	26	22	19	17	15	41.6
20000 cfs						42	42	42	42	42	41	41	40	39	38	38	36	34	32	29	26	22	19	17	15	41.7
19000 cfs							42	42	42	42	41	41	40	39	38	38	36	34	32	29	26	23	19	17	15	41.7
18000 cfs								42	42	42	41	41	40	39	39	38	36	34	32	29	26	23	19	17	15	41.7
17000 cfs									42	42	42	41	40	39	39	38	36	35	32	30	26	23	20	17	15	41.8
16000 cfs										42	42	41	40	40	39	38	37	35	33	30	26	23	20	17	15	42.0
15000 cfs											42	41	41	40	39	39	37	35	33	30	27	23	20	17	16	42.1
14000 cfs												41	40	39	39	38	37	35	32	30	26	23	20	17	15	40.8
13000 cfs													41	41	40	39	38	35	33	30	26	23	19	16	15	41.4
12000 cfs														42	41	40	39	36	33	30	26	23	19	16	14	42.0
11000 cfs															41	40	38	35	32	29	25	22	18	15	13	41.0
10000 cfs																39	37	34	31	27	24	21	17	14	12	39.1
9000 cfs																	35	32	29	26	23	19	16	13	11	34.8
8000 cfs																		30	27	24	22	19	16	13	11	30.1
7000 cfs																			25	23	20	18	16	13	11	25.3
6000 cfs																				22	20	18	15	13	11	21.6
5000 cfs																					20	18	15	13	11	19.8
4000 cfs																						18	16	13	11	17.9
3000 cfs																							16	13	11	15.9
2000 cfs																								13	11	13.2
1000 cfs																									11	11.3

Spawning Discharge (cfs)	Ending Incubation Discharge (cfs)																								
	25000	24000	23000	22000	21000	20000	19000	18000	17000	16000	15000	14000	13000	12000	11000	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000
25000 cfs	100	100	100	100	100	100	100	100	100	100	99	97	96	94	92	90	87	82	76	69	61	53	46	40	36
24000 cfs		100	100	100	100	100	100	100	100	100	99	97	96	94	92	90	87	82	76	69	61	53	46	40	36
23000 cfs			100	100	100	100	100	100	100	100	99	97	96	94	92	90	87	82	76	69	61	54	46	40	36
22000 cfs				100	100	100	100	100	100	100	99	97	96	94	92	90	87	82	76	70	62	54	46	40	36
21000 cfs					100	100	100	100	100	100	99	97	96	94	92	90	87	82	76	70	62	54	46	40	36
20000 cfs						100	100	100	100	100	99	97	96	94	92	90	87	82	76	70	62	54	46	40	36
19000 cfs							100	100	100	100	99	98	96	94	92	90	87	82	77	70	62	54	47	40	36
18000 cfs								100	100	100	99	98	96	94	92	90	87	82	77	70	62	54	47	40	36
17000 cfs									100	100	99	98	96	95	93	91	87	83	77	71	63	54	47	40	36
16000 cfs										100	100	98	96	95	93	91	88	83	78	71	63	55	47	41	36
15000 cfs											100	98	97	95	93	91	88	84	78	72	64	55	48	41	37
14000 cfs												100	98	97	95	93	90	85	79	72	64	56	48	41	37
13000 cfs													100	98	97	94	91	85	79	72	64	55	47	40	35
12000 cfs														100	98	96	92	86	79	71	63	54	46	38	33
11000 cfs															100	98	93	86	78	70	62	53	45	37	32
10000 cfs																100	94	87	78	70	61	53	44	36	31
9000 cfs																	100	92	83	74	65	56	47	38	32
8000 cfs																		100	90	81	71	62	52	42	35
7000 cfs																			100	90	81	71	61	50	42
6000 cfs																				100	91	81	71	59	50
5000 cfs																					100	89	78	65	55
4000 cfs																						100	88	73	62
3000 cfs																							100	84	71
2000 cfs																								100	84
1000 cfs																									100

Table 7. Effective Spawning and Incubation Habitat Amount (ft^2/1000 ft) (top) and Percent (bottom) in Spawning Patches Ranked 1 - 2.

Spawning Discharge (cfs)	Ending Incubation Discharge (cfs)																									Total
	25000	24000	23000	22000	21000	20000	19000	18000	17000	16000	15000	14000	13000	12000	11000	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000	(ft^2)
25000 cfs	46	46	46	46	46	46	46	46	46	46	45	44	43	42	41	40	38	35	33	30	26	23	20	17	15	46.1
24000 cfs		46	46	46	46	46	46	46	46	46	45	44	43	42	41	40	38	36	33	30	26	23	20	17	15	46.2
23000 cfs			46	46	46	46	46	46	46	46	45	45	44	43	41	40	38	36	33	30	26	23	20	17	15	46.3
22000 cfs				46	46	46	46	46	46	46	46	45	44	43	41	40	38	36	33	30	27	23	20	17	15	46.4
21000 cfs					47	47	46	46	46	46	46	45	44	43	42	40	38	36	33	30	27	23	20	17	15	46.5
20000 cfs						47	47	46	46	46	46	45	44	43	42	40	39	36	33	30	27	23	20	17	15	46.6
19000 cfs							47	46	46	46	46	45	44	43	42	40	39	36	33	30	27	23	20	17	15	46.6
18000 cfs								46	46	46	46	45	44	43	42	41	39	36	33	30	27	24	20	17	15	46.5
17000 cfs									46	46	46	45	44	43	42	41	39	36	34	31	27	24	20	17	15	46.4
16000 cfs										46	46	45	44	43	42	41	39	37	34	31	27	24	21	17	15	46.5
15000 cfs											46	46	45	44	43	41	39	37	34	31	28	24	21	18	16	46.4
14000 cfs												45	44	43	42	41	39	37	34	31	27	24	20	17	15	44.9
13000 cfs													45	44	43	42	40	37	34	31	27	24	20	17	15	44.9
12000 cfs														45	44	43	41	38	35	31	27	24	20	16	14	45.2
11000 cfs															44	42	40	37	33	30	26	23	19	16	13	43.7
10000 cfs																41	39	36	32	28	25	22	18	15	12	41.4
9000 cfs																	37	34	30	27	24	20	17	14	11	36.7
8000 cfs																		32	28	25	23	20	17	13	11	31.7
7000 cfs																			27	24	21	19	16	13	11	26.5
6000 cfs																				23	21	19	16	13	11	22.7
5000 cfs																					21	19	16	13	11	20.9
4000 cfs																						19	17	14	12	19.1
3000 cfs																							17	14	12	17.1
2000 cfs																								14	12	14.4
1000 cfs																									12	12.4

Spawning Discharge (cfs)	Ending Incubation Discharge (cfs)																								
	25000	24000	23000	22000	21000	20000	19000	18000	17000	16000	15000	14000	13000	12000	11000	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000
25000 cfs	100	100	100	100	100	100	100	100	99	99	98	96	94	92	89	86	82	77	71	64	57	50	43	36	32
24000 cfs		100	100	100	100	100	100	100	99	99	98	96	94	92	89	86	82	77	71	64	57	50	43	36	32
23000 cfs			100	100	100	100	100	100	99	99	98	96	94	92	89	86	82	77	71	65	57	50	43	36	32
22000 cfs				100	100	100	100	100	99	99	98	96	94	92	89	86	82	77	71	65	57	50	43	36	32
21000 cfs					100	100	100	100	99	99	98	96	94	92	89	87	83	77	71	65	57	50	43	36	32
20000 cfs						100	100	100	99	99	98	96	94	92	89	87	83	77	71	65	58	50	43	36	32
19000 cfs							100	100	100	99	98	96	94	92	90	87	83	78	72	65	58	50	43	36	32
18000 cfs								100	100	99	99	97	95	93	90	87	83	78	72	66	58	51	44	37	32
17000 cfs									100	100	99	97	95	93	90	88	84	78	72	66	58	51	44	37	33
16000 cfs										100	99	97	95	93	91	88	84	79	73	67	59	52	44	37	33
15000 cfs											100	98	96	94	92	89	85	80	74	67	60	52	45	38	34
14000 cfs												100	98	96	93	91	87	81	75	68	61	53	45	38	34
13000 cfs													100	98	96	93	88	83	76	69	61	53	45	37	33
12000 cfs														100	98	95	90	84	76	69	61	52	45	36	31
11000 cfs															100	97	92	84	76	68	60	52	44	36	30
10000 cfs																100	94	86	77	69	61	52	44	35	29
9000 cfs																	100	92	82	73	64	56	47	37	31
8000 cfs																		100	90	80	71	62	52	41	34
7000 cfs																			100	90	81	72	62	49	41
6000 cfs																				100	91	82	72	58	49
5000 cfs																					100	90	79	65	54
4000 cfs																						100	88	73	62
3000 cfs																							100	84	71
2000 cfs																								100	84
1000 cfs																									100

Table 8. Effective Spawning and Incubation Habitat Amount (ft2/1000 ft) (top) and Percent (bottom) in Spawning Patches Ranked 1 - 3.

Spawning Discharge	Ending Incubation Discharge (cfs)																									Total
(cfs)	25000	24000	23000	22000	21000	20000	19000	18000	17000	16000	15000	14000	13000	12000	11000	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000	(ft^2)
25000 cfs	49	49	49	49	49	49	49	49	49	49	48	47	46	45	44	42	40	37	34	30	27	23	20	17	15	49.2
24000 cfs		49	49	49	49	49	49	49	49	49	48	47	46	45	44	42	40	37	34	30	27	23	20	17	15	49.3
23000 cfs			49	49	49	49	49	49	49	49	48	47	46	45	44	42	40	37	34	30	27	23	20	17	15	49.4
22000 cfs				49	49	49	49	49	49	49	49	48	46	45	44	42	40	37	34	31	27	24	20	17	15	49.5
21000 cfs					50	50	50	49	49	49	49	48	47	45	44	43	40	38	34	31	27	24	20	17	15	49.6
20000 cfs						50	50	49	49	49	49	48	47	46	44	43	41	38	34	31	27	24	20	17	15	49.7
19000 cfs							50	49	49	49	49	48	47	46	44	43	41	38	34	31	27	24	20	17	15	49.6
18000 cfs								49	49	49	49	48	47	46	44	43	41	38	34	31	27	24	20	17	15	49.4
17000 cfs									49	49	49	48	47	46	44	43	41	38	35	31	28	24	21	17	15	49.3
16000 cfs										49	49	48	47	46	45	43	41	38	35	32	28	24	21	17	15	49.3
15000 cfs											49	48	47	46	45	43	41	39	35	32	28	25	21	18	16	49.1
14000 cfs												47	47	45	44	43	41	38	35	31	28	24	21	17	15	47.5
13000 cfs													47	46	45	44	42	39	35	31	28	24	21	17	15	47.4
12000 cfs														47	46	45	42	39	35	32	28	24	20	17	14	47.4
11000 cfs															46	44	42	38	34	30	27	23	20	16	13	45.7
10000 cfs																43	40	37	33	29	25	22	18	15	12	43.1
9000 cfs																	38	35	31	27	24	21	17	14	11	38.2
8000 cfs																		33	29	26	23	20	17	13	11	32.9
7000 cfs																			27	24	22	19	17	13	11	27.3
6000 cfs																				23	21	19	16	13	11	23.2
5000 cfs																					21	19	17	14	11	21.2
4000 cfs																						19	17	14	12	19.2
3000 cfs																							17	14	12	17.1
2000 cfs																								14	12	14.4
1000 cfs																									12	12.4

Spawning Discharge	Ending Incubation Discharge (cfs)																								
(cfs)	25000	24000	23000	22000	21000	20000	19000	18000	17000	16000	15000	14000	13000	12000	11000	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000
25000 cfs	100	100	100	100	100	100	100	100	99	99	98	96	94	92	89	86	81	75	68	61	54	47	41	34	30
24000 cfs		100	100	100	100	100	100	100	99	99	98	96	94	92	89	86	81	75	69	62	54	47	41	34	30
23000 cfs			100	100	100	100	100	100	99	99	98	96	94	92	89	86	81	75	69	62	55	47	41	34	30
22000 cfs				100	100	100	100	100	99	99	98	96	94	92	89	86	82	76	69	62	55	48	41	34	30
21000 cfs					100	100	100	100	99	99	98	96	94	92	89	86	82	76	69	62	55	48	41	34	30
20000 cfs						100	100	100	99	99	98	96	94	92	89	86	82	76	69	62	55	48	41	34	30
19000 cfs							100	100	100	99	98	96	94	92	89	86	82	76	69	62	55	48	41	34	30
18000 cfs								100	100	99	99	97	94	92	89	86	82	76	70	63	56	48	41	35	31
17000 cfs									100	100	99	97	95	93	90	87	83	77	70	63	56	49	42	35	31
16000 cfs										100	99	97	95	93	90	87	83	78	71	64	57	49	42	35	31
15000 cfs											100	98	96	94	91	88	84	79	72	65	58	50	43	36	32
14000 cfs												100	98	96	93	90	86	80	73	66	58	51	44	36	32
13000 cfs													100	98	95	92	88	81	74	66	59	51	43	36	31
12000 cfs														100	97	94	89	82	75	67	59	51	43	35	30
11000 cfs															100	97	91	84	75	67	59	51	43	34	29
10000 cfs																100	94	85	76	67	59	51	43	34	29
9000 cfs																	100	91	81	72	63	54	46	36	30
8000 cfs																		100	89	79	70	61	51	40	33
7000 cfs																			100	89	80	71	61	49	40
6000 cfs																				100	91	81	71	57	48
5000 cfs																					100	90	78	64	54
4000 cfs																						100	88	73	61
3000 cfs																							100	84	71
2000 cfs																								100	84
1000 cfs																									100

FIGURES

Figure 1. Technical Study Plan Objectives and Study Elements.

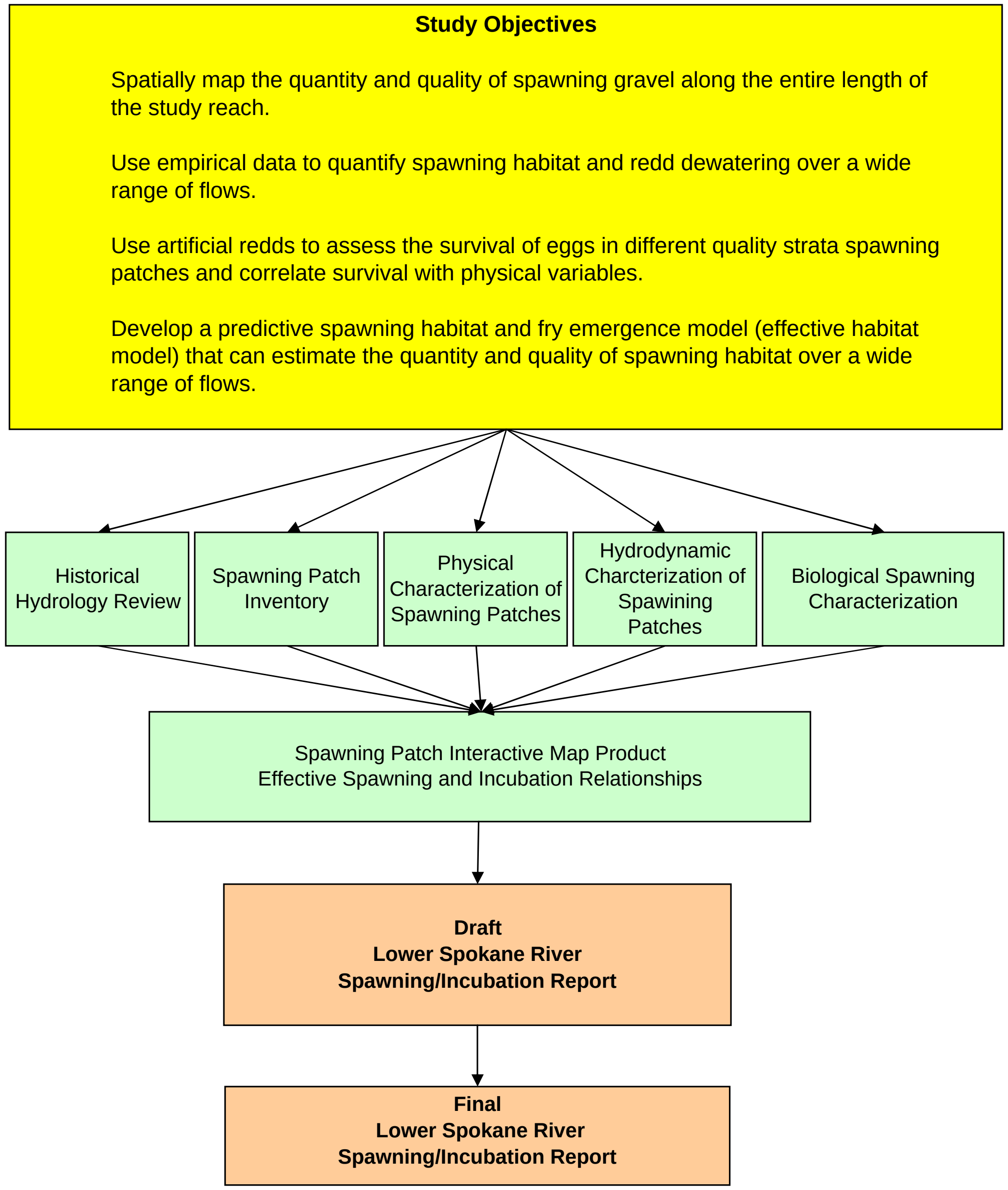


Figure 2a. Spokane River Average Daily Flow Data (1980 – 2010) Measured at the Spokane River Near Spokane, WA (USGS Gage 12422500).

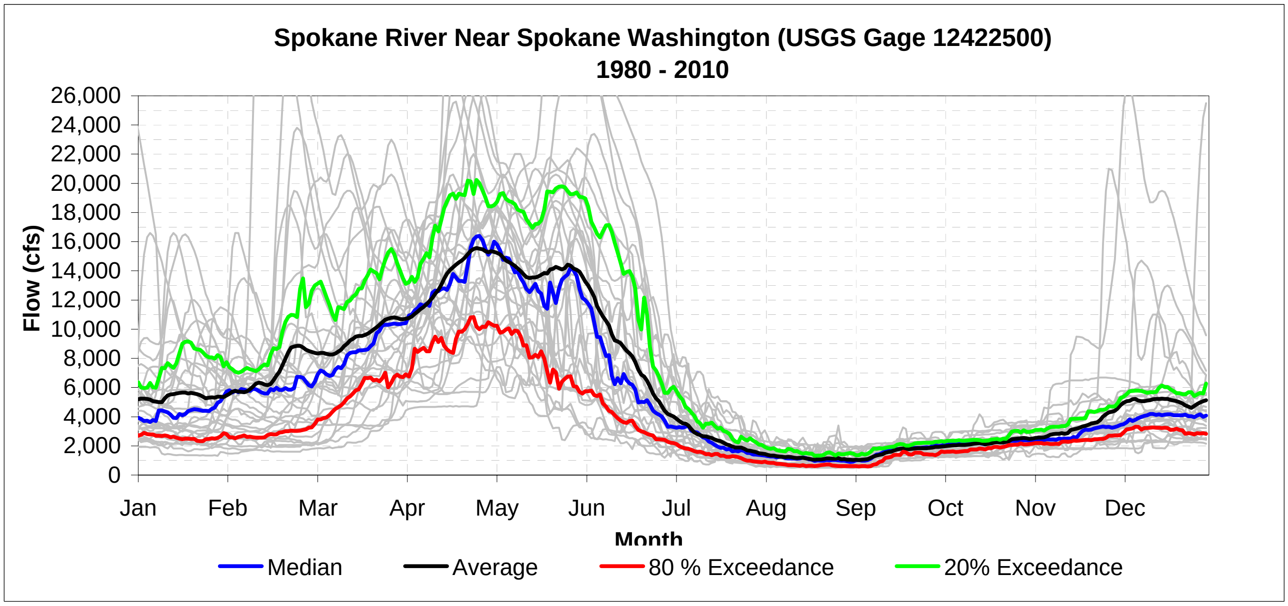


Figure 2b. Spokane River Flow Data (March 1 - August 1, 2010) Measured at the Spokane River Near Spokane, WA (USGS Gage 12422500).

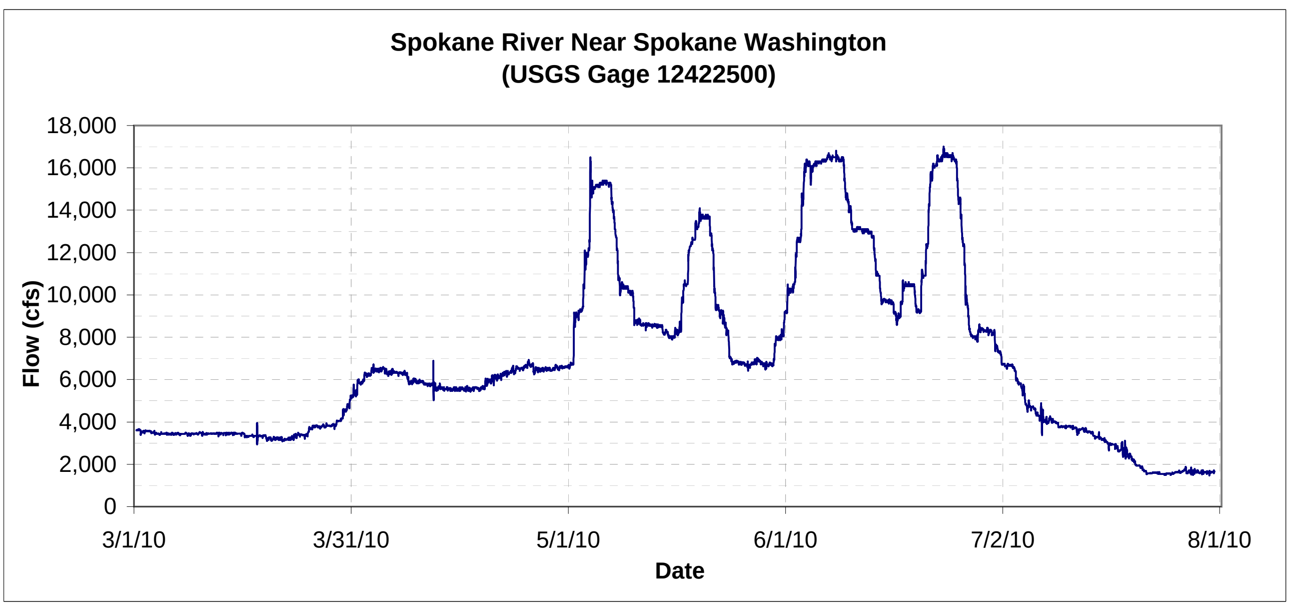
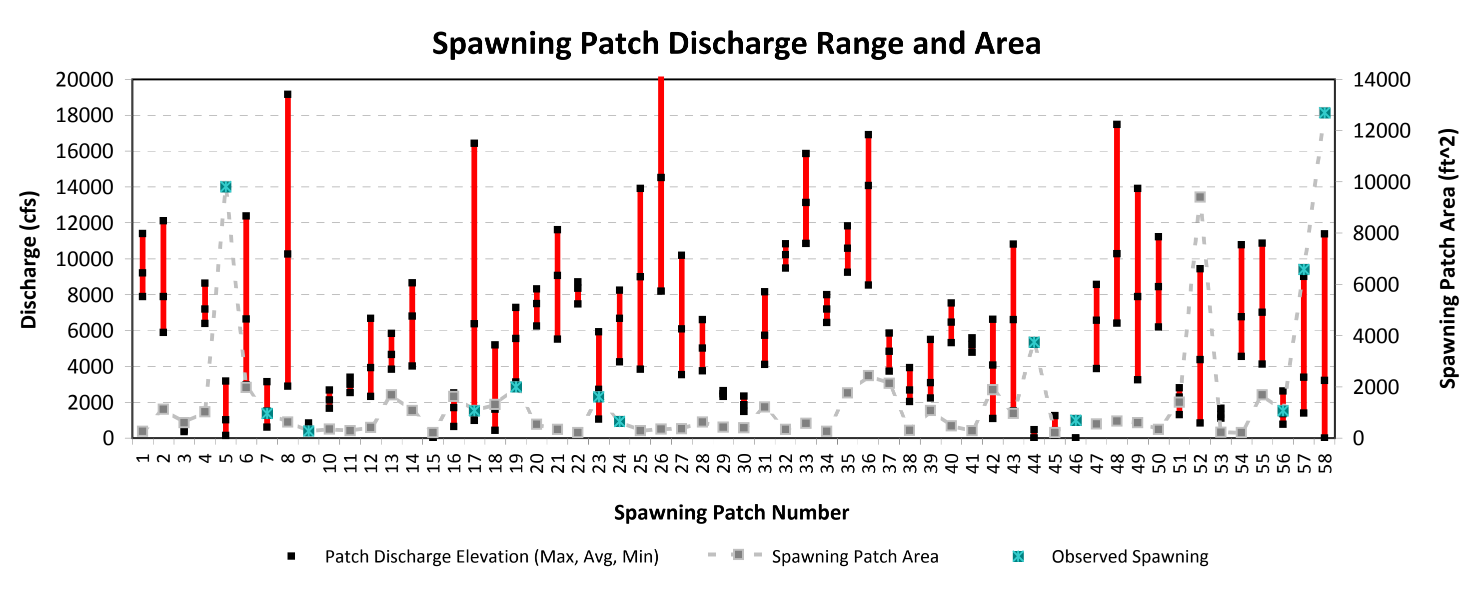


Figure 3. Spawning Patch Discharge Range and Area (top) and Cummulative Spawning Patch Area Based on Average Elevation (bottom).



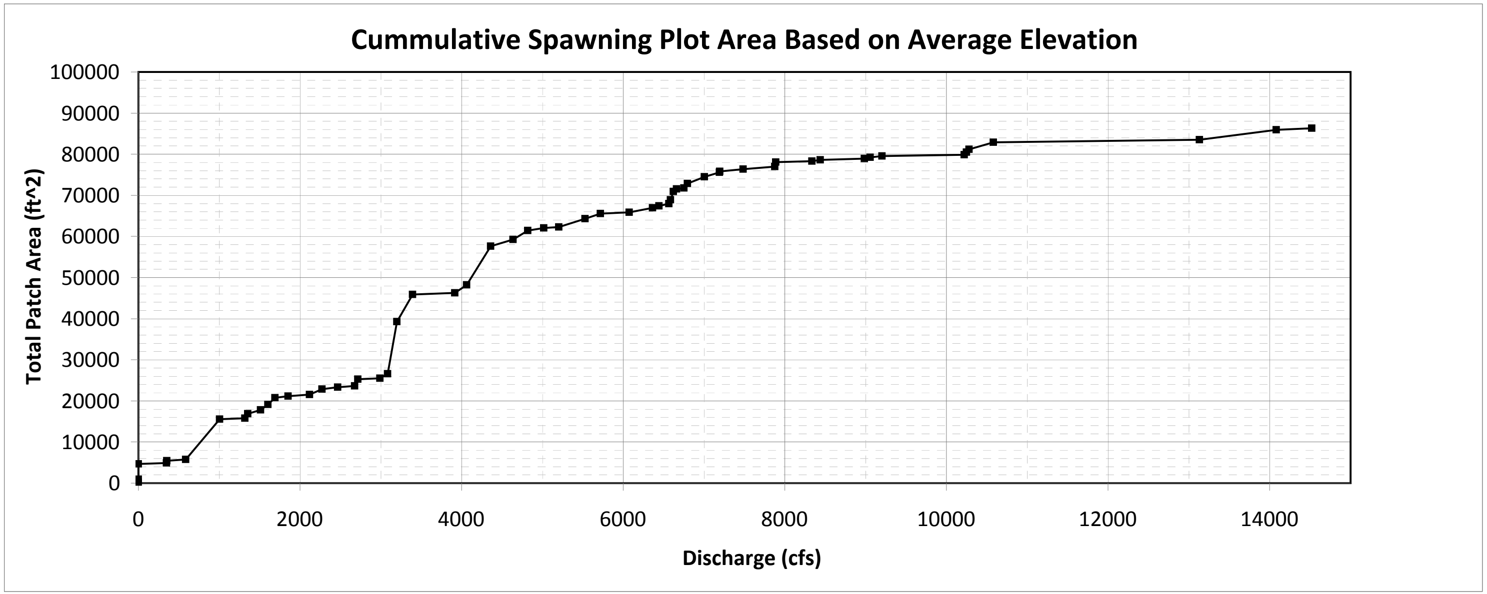
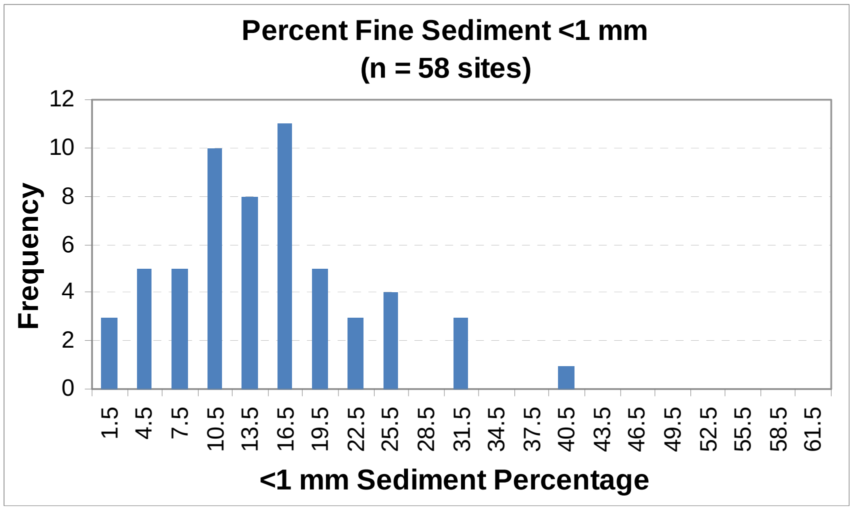


Figure 4. Percent Fine Sediment (top) and Mean Particle Size (bottom) at the 58 Spawning Patch Locaitons.



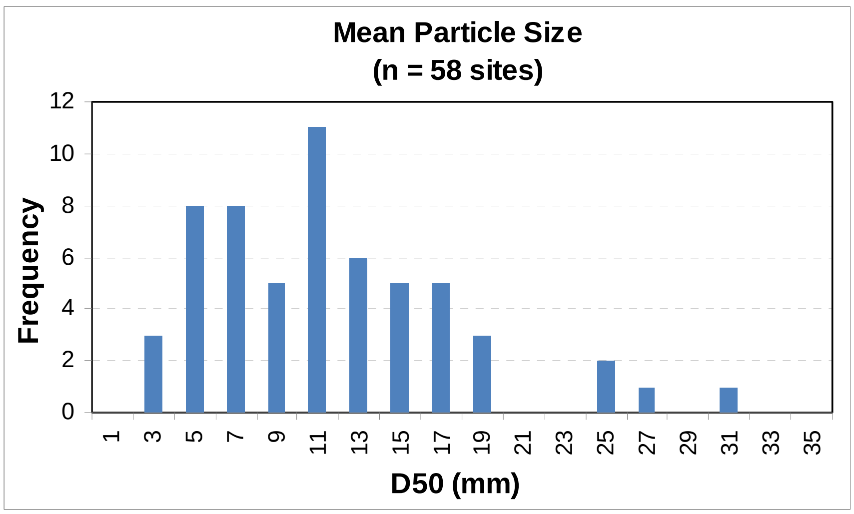


Figure 5. Comparison of Average Daily Discharge Measured at the Spokane River Near Spokane, WA (USGS Gage 12422500) and Total Daily Redd Counts for the 2010 Spawning Surveys.

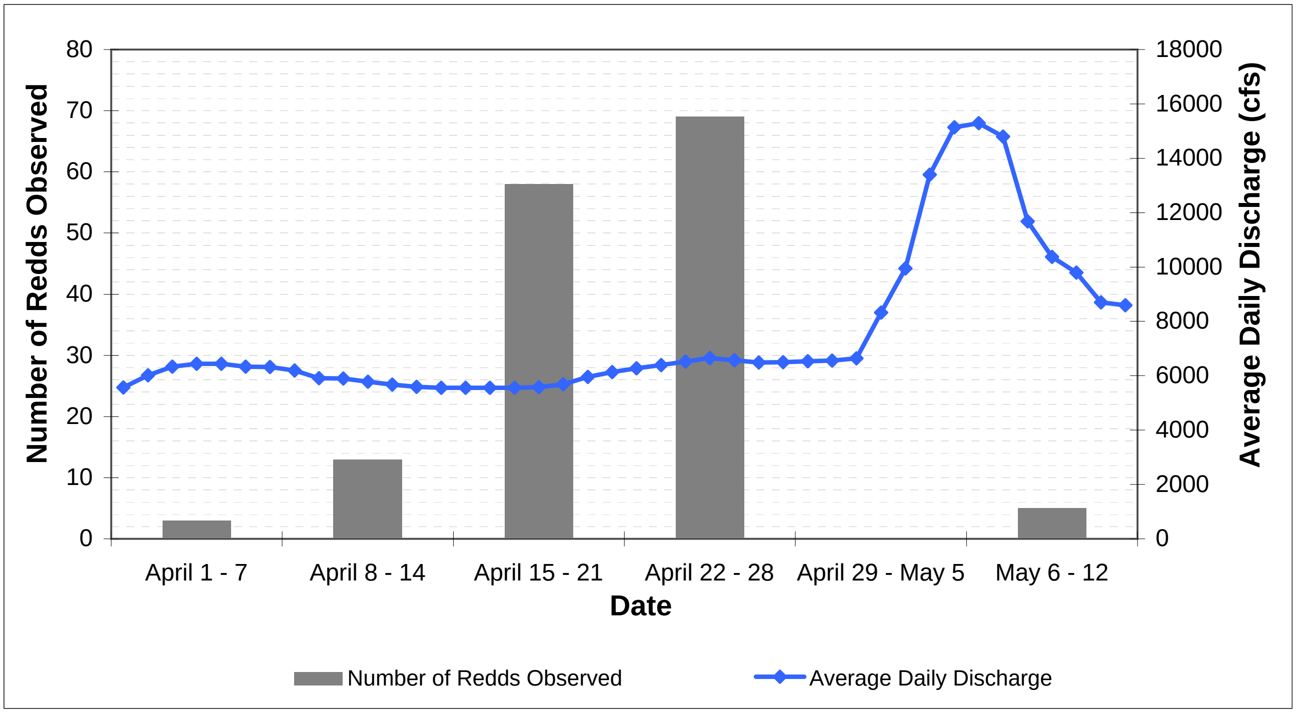
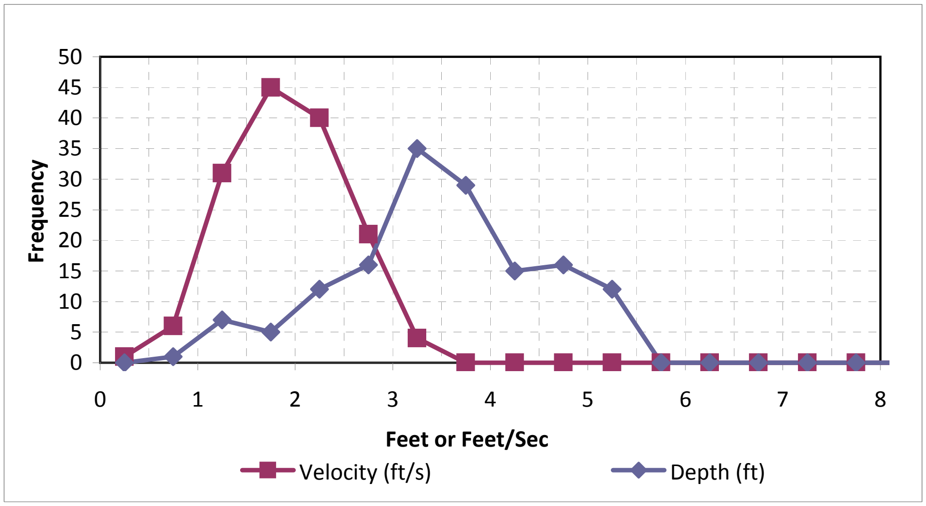


Figure 6. Observed 2010 Redband Trout Depth and Velocity Spawning Frequency (top) and Percent of Maximum Frequency (bottom) (n = 148 redds).



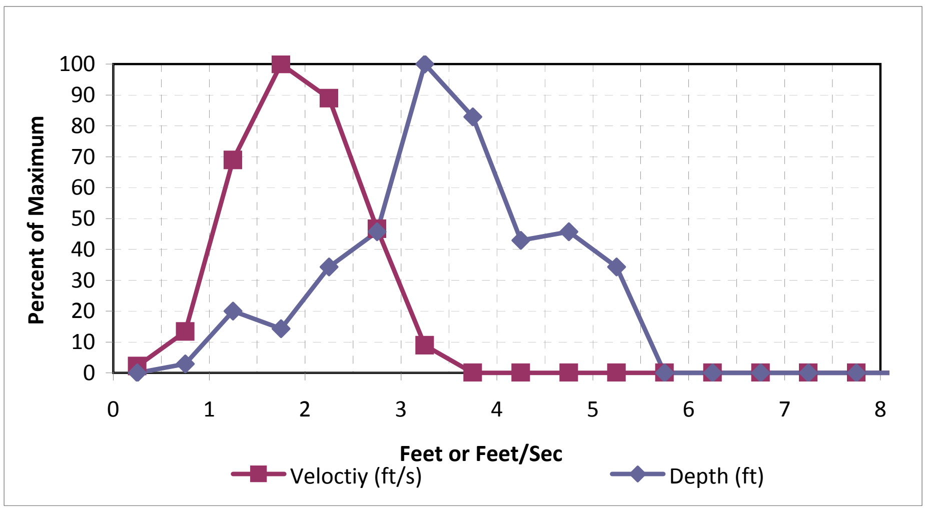


Figure 7. Artificial Redd Percent Survival Versus Fine Sediment Intrusion.

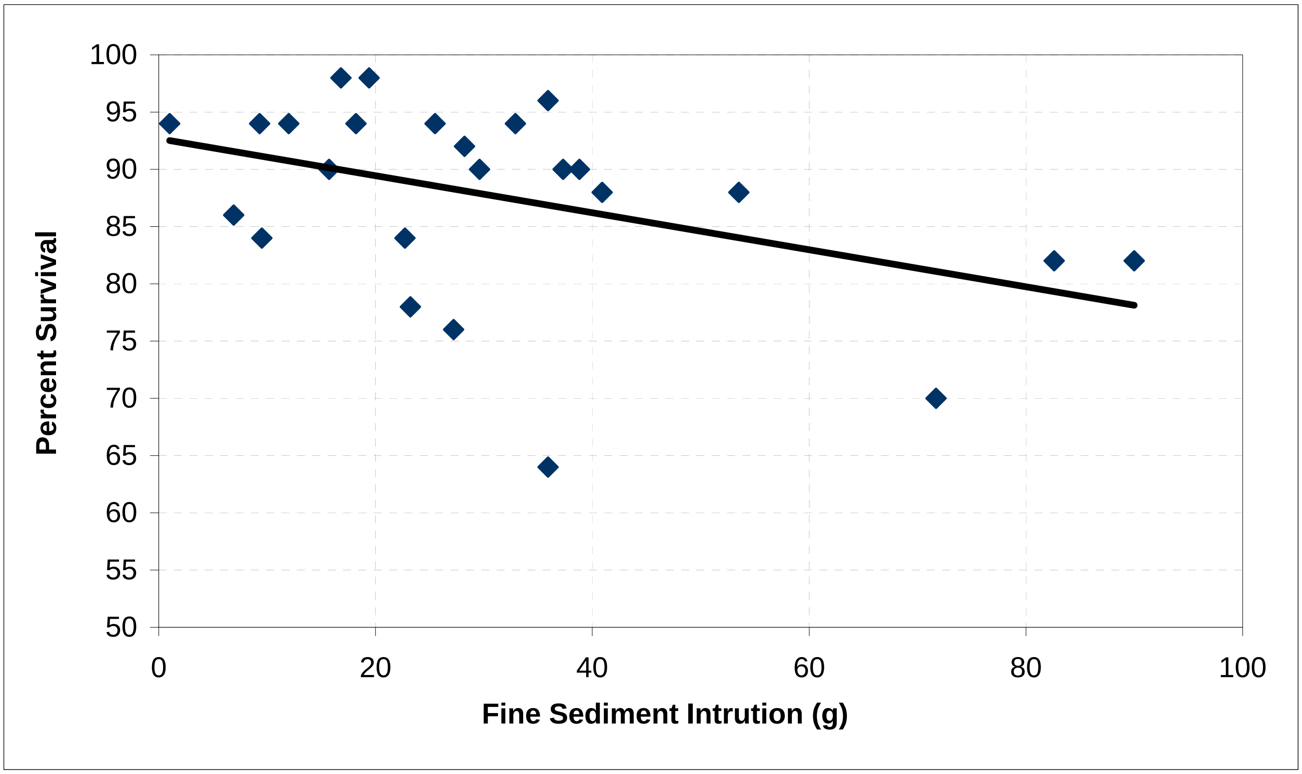


Figure 8. Artificial Redd Percent Survival Versus Percent Clod Card Dissolution.

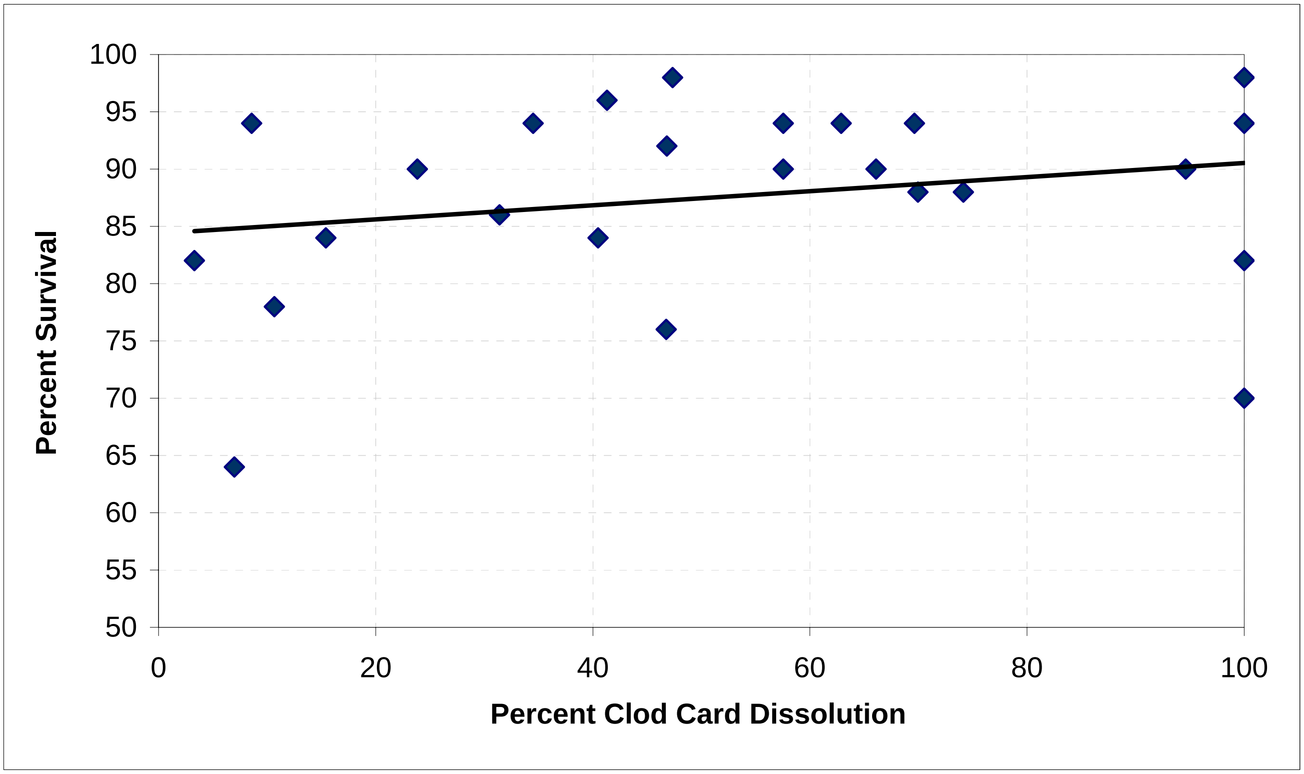


Figure 9. Artificial Redd Percent Survival Versus Dissolved Oxygen (Day 18 and Day 27).

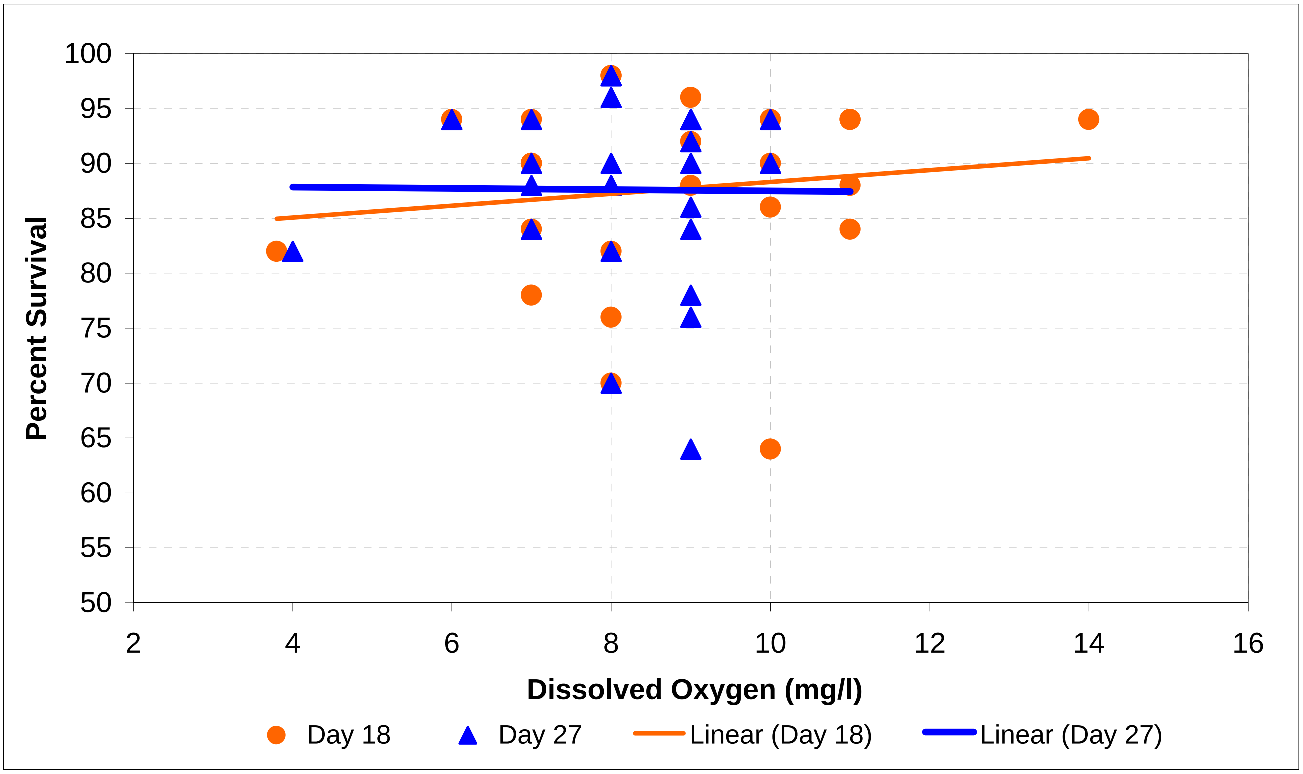


Figure 10. Artificial Redd Percent Survival Versus Average Temperature.

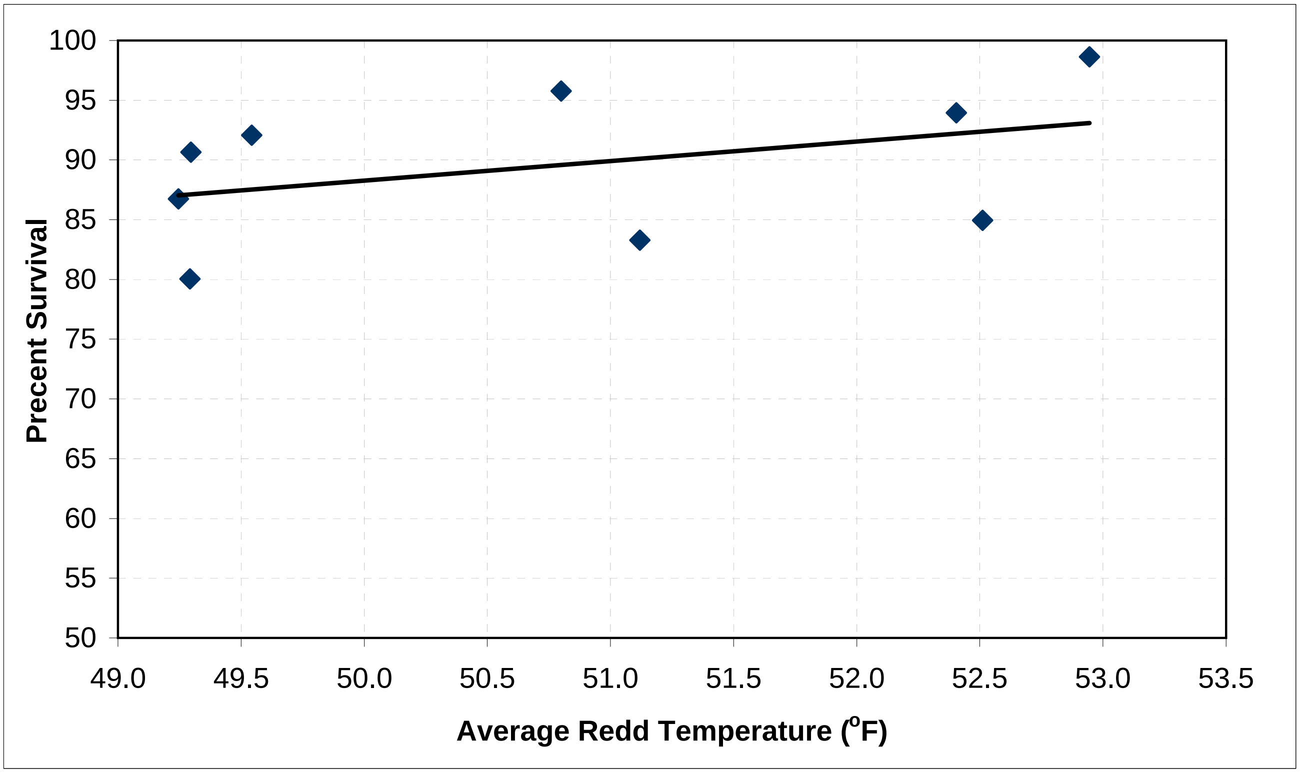


Figure 11. Water Temperature at Artificial Redd Study Sites.

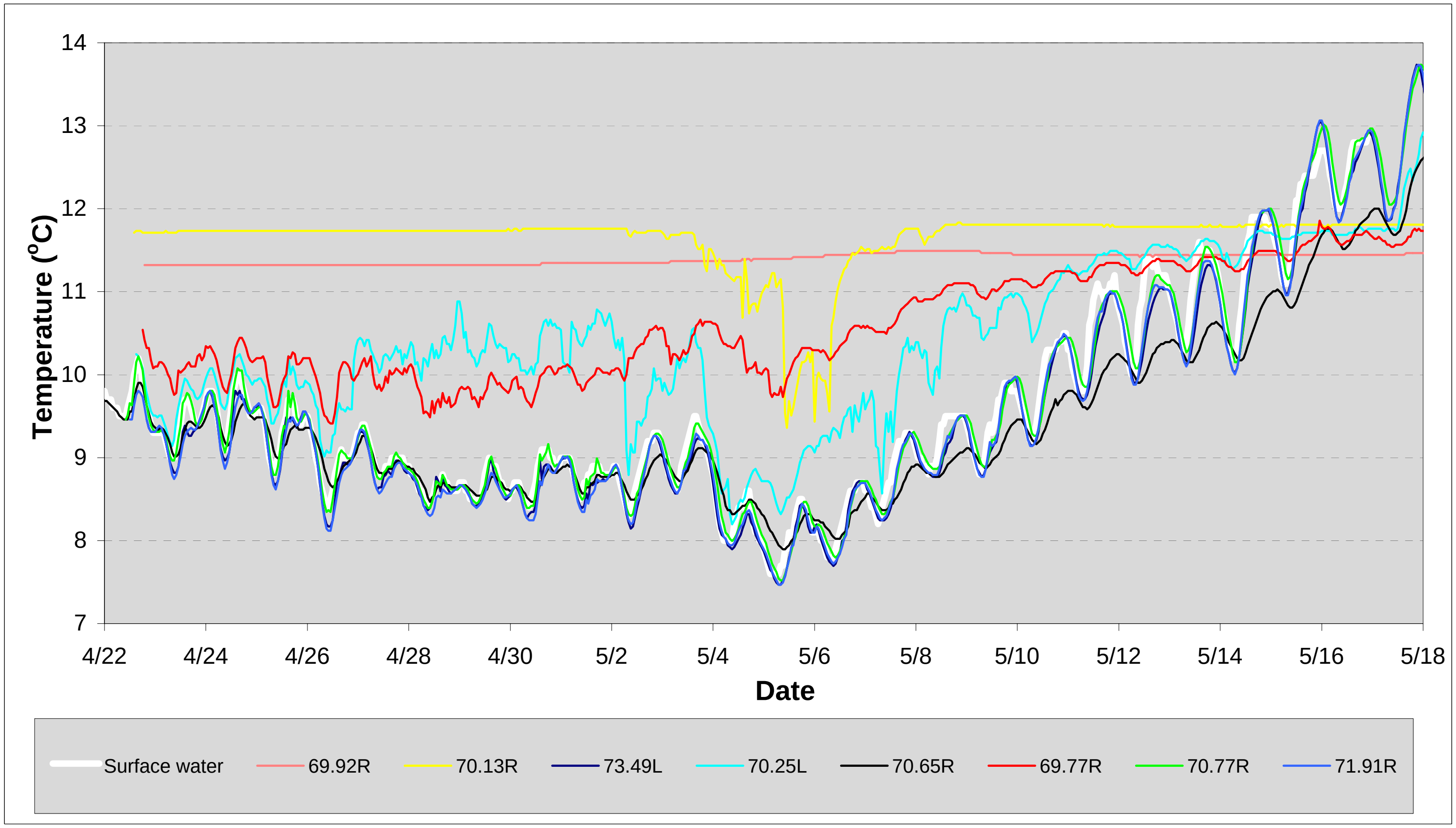
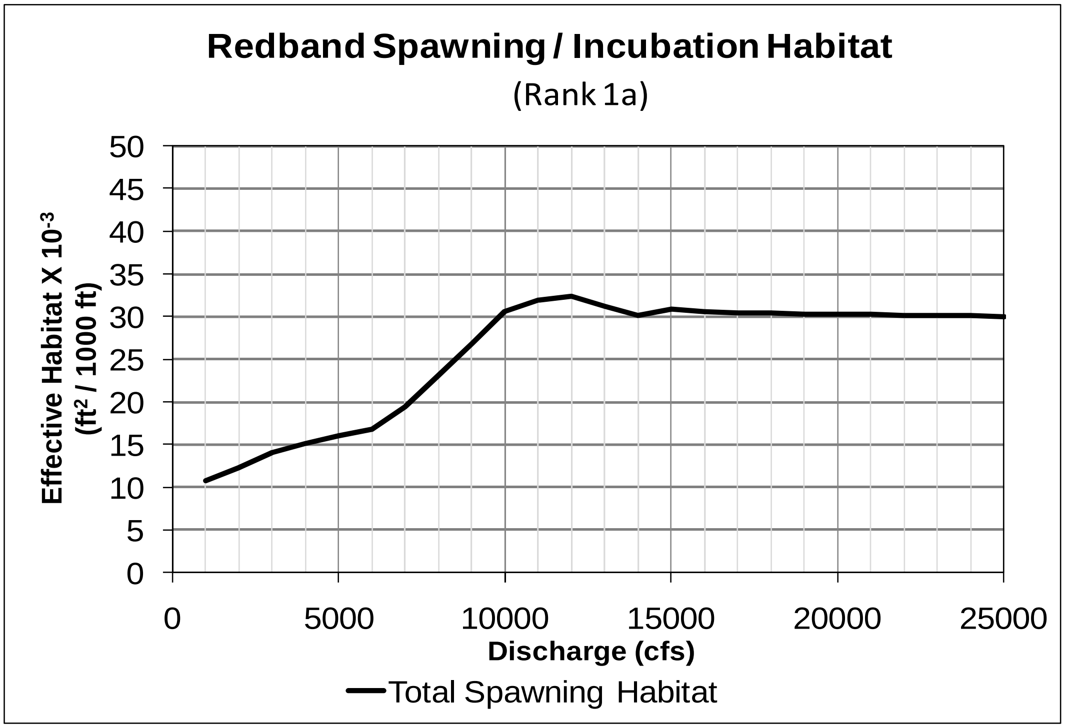


Figure 12. Amount (ft^2/1000 ft) (top) and Percent (bottom) of Effective Spawning Habitat in Spawning Patches Ranked 1a.



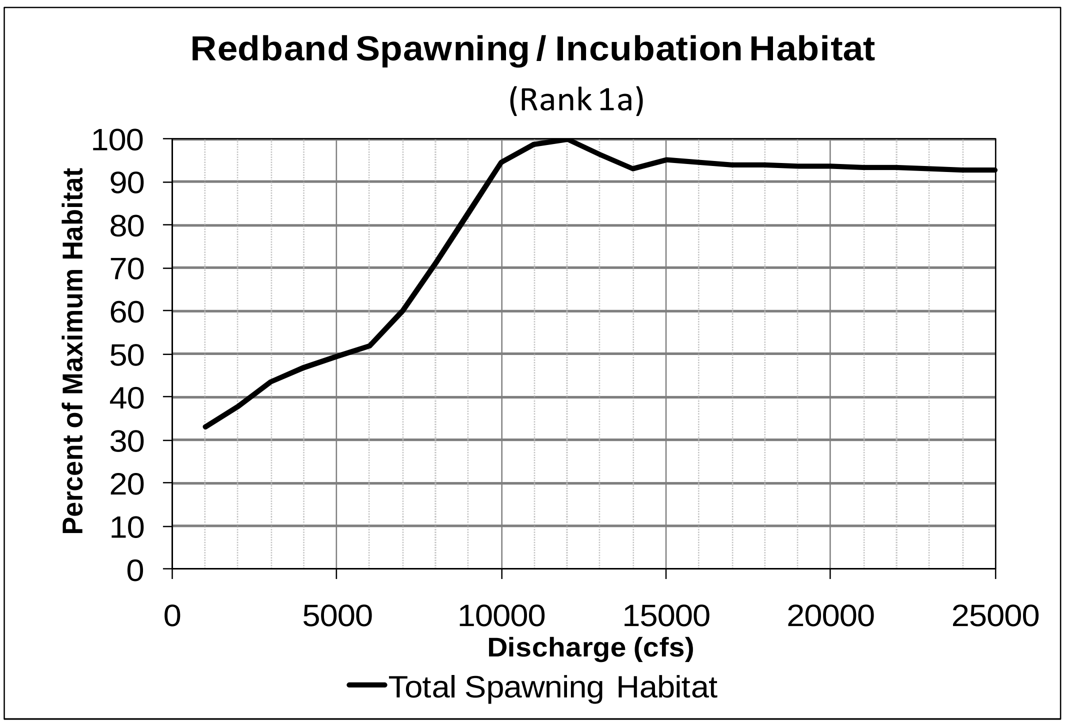
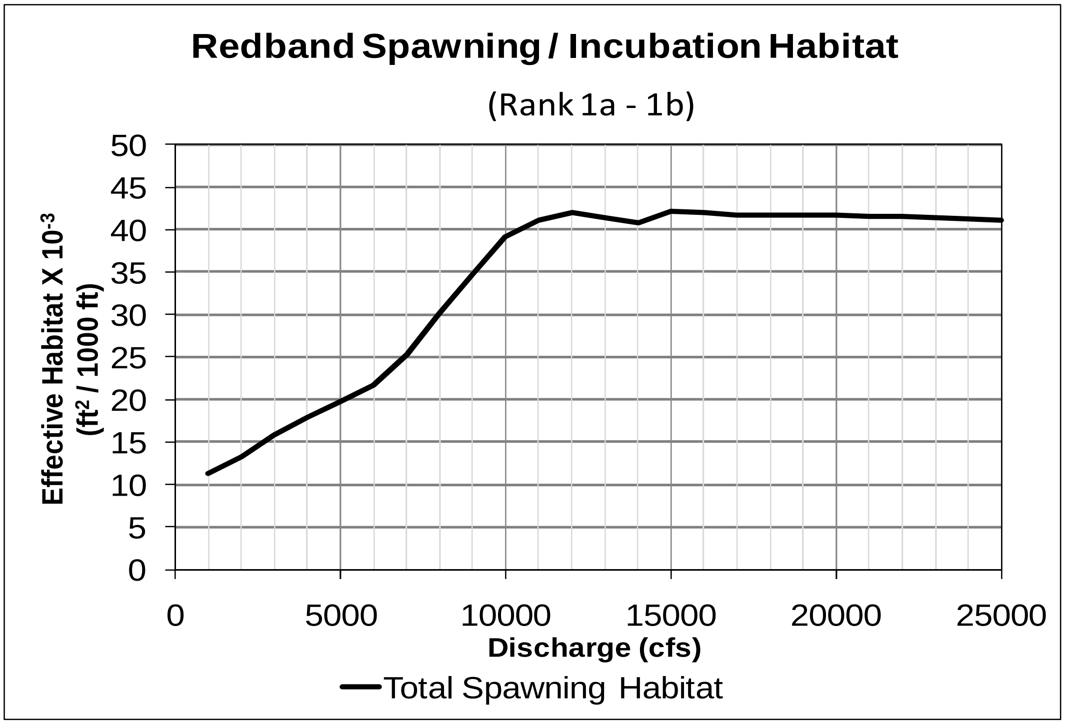


Figure 13. Amount (ft^2/1000 ft) (top) and Percent (bottom) of Effective Spawning Habitat in Spawning Patches Ranked 1a-1b.



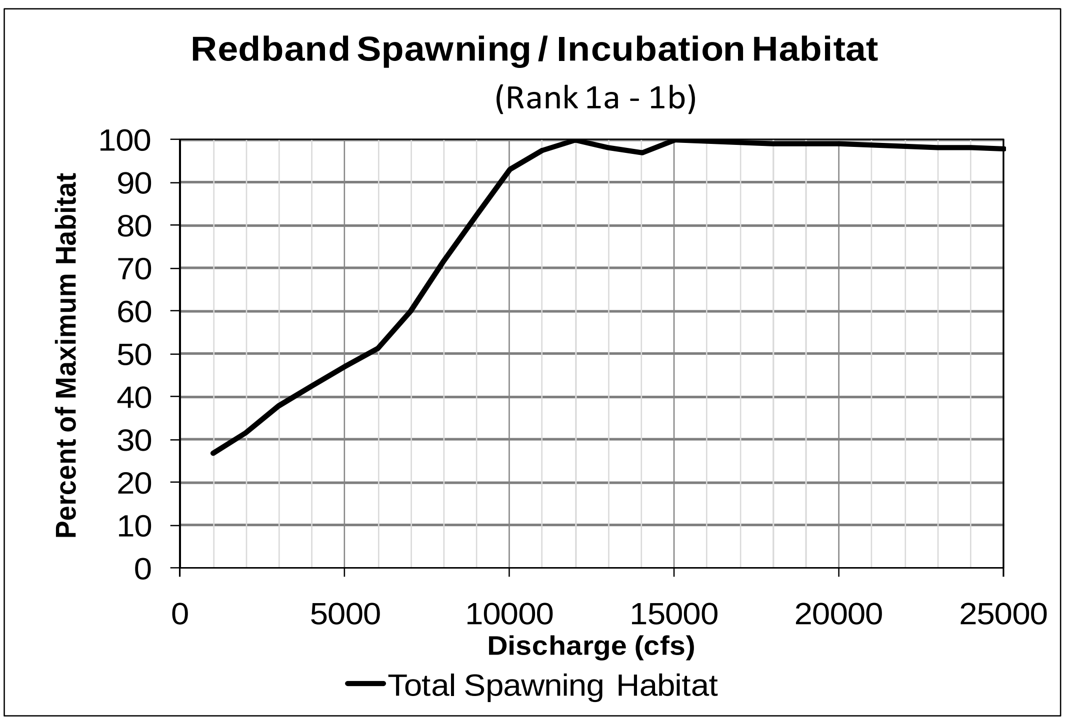
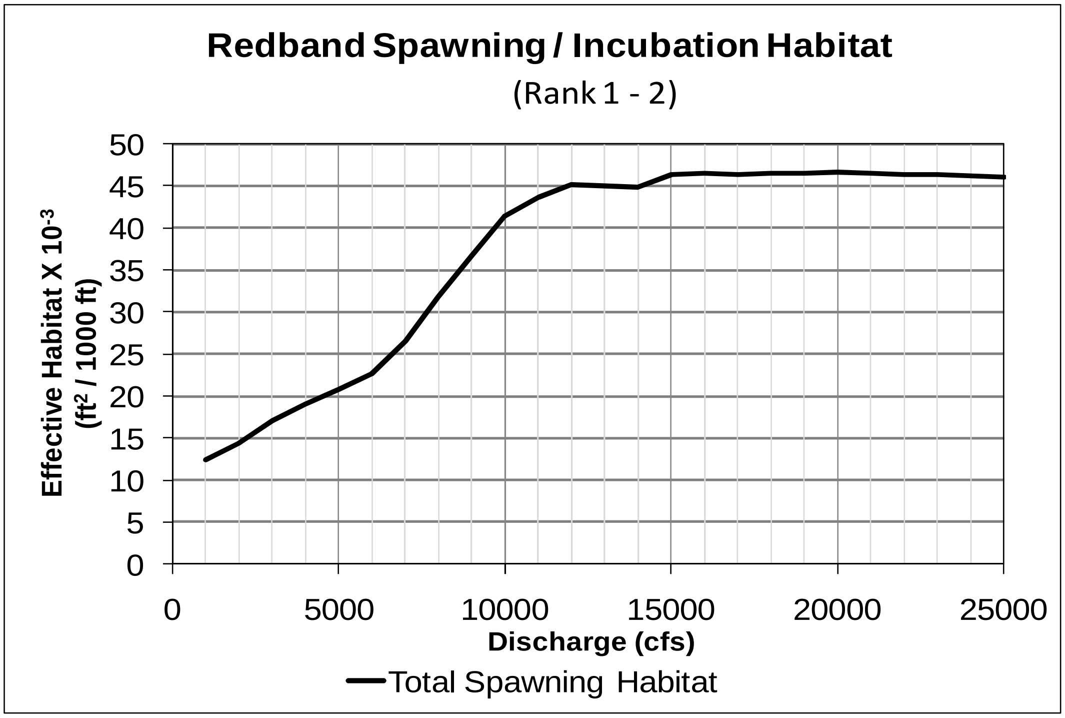


Figure 14. Amount (ft^2/1000 ft) (top) and Percent (bottom) of Effective Spawning Habitat in Spawning Patches Ranked 1-2.



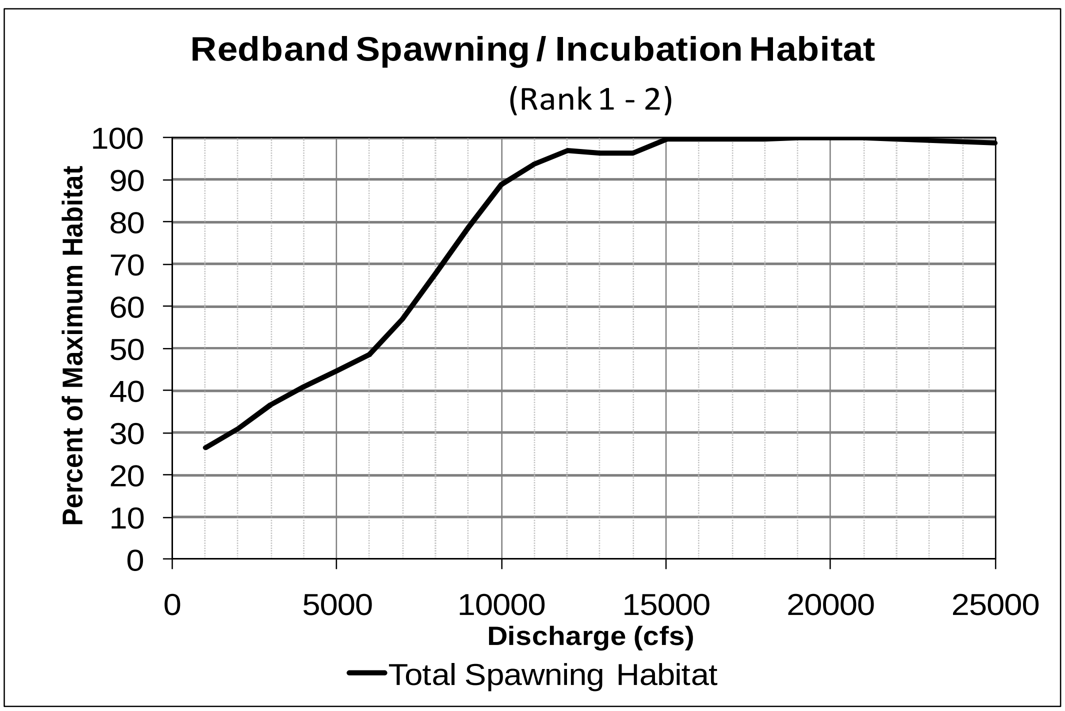
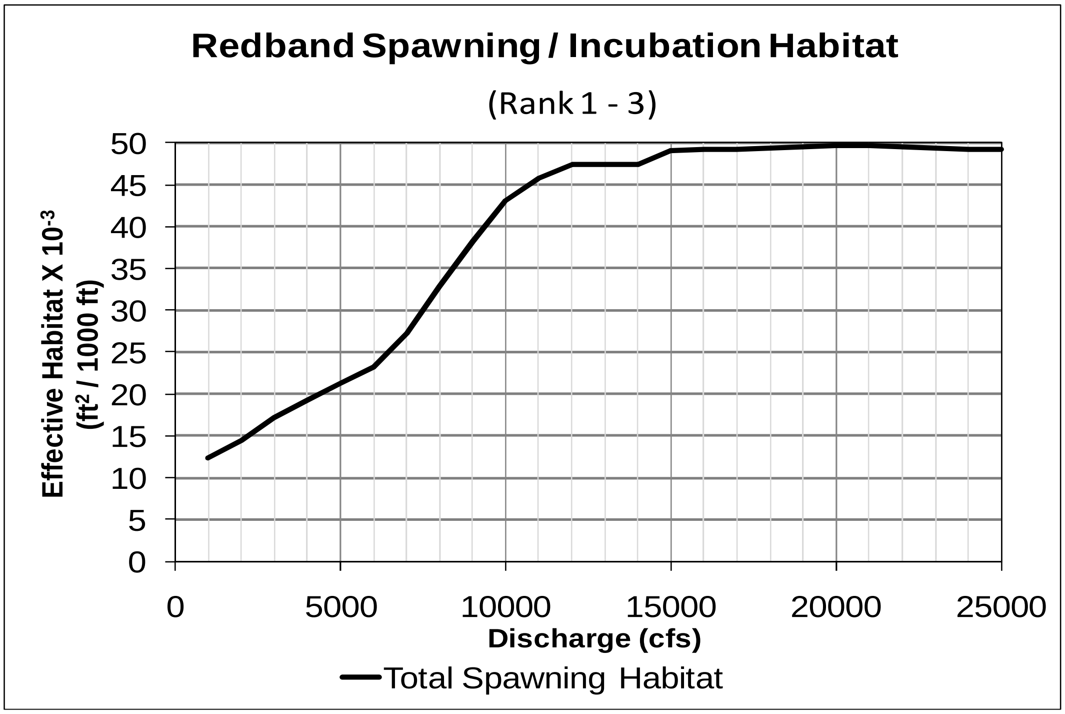


Figure 15. Amount (ft^2/1000 ft) (top) and Percent (bottom) of Effective Spawning Habitat in Spawning Patches Ranked 1-3.



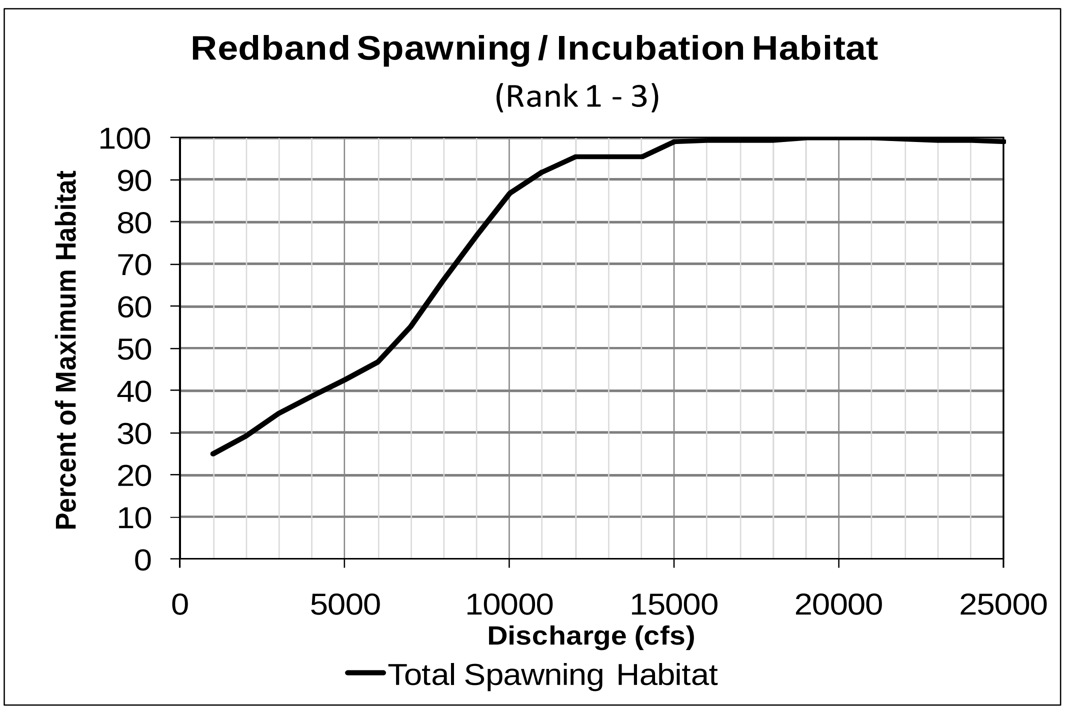
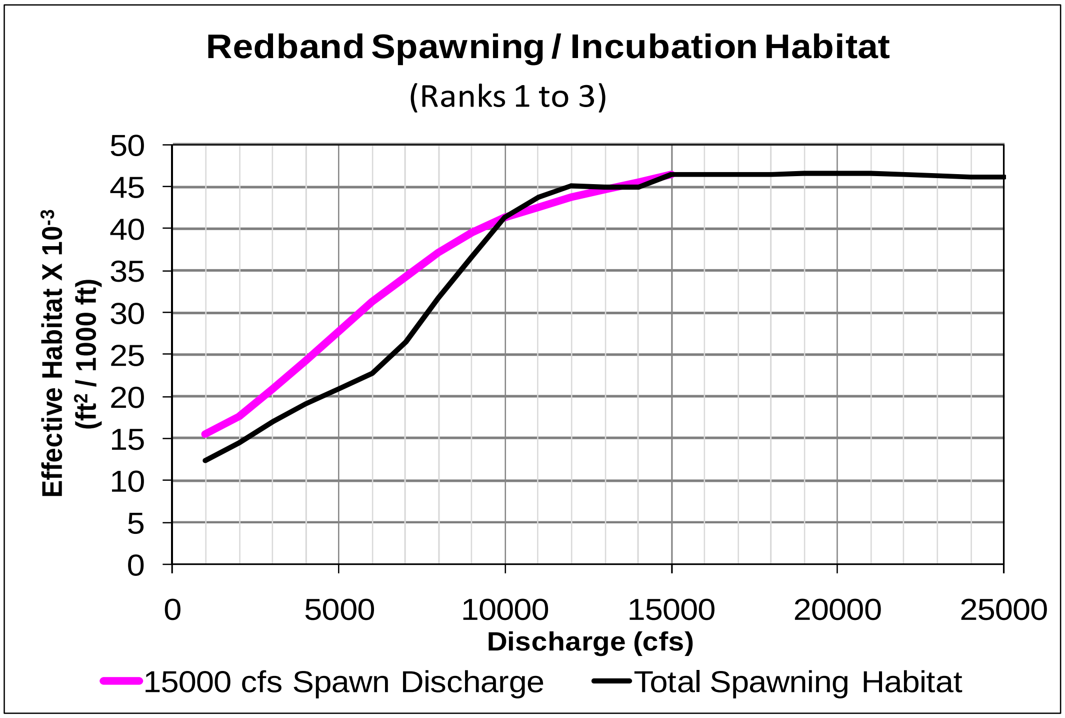
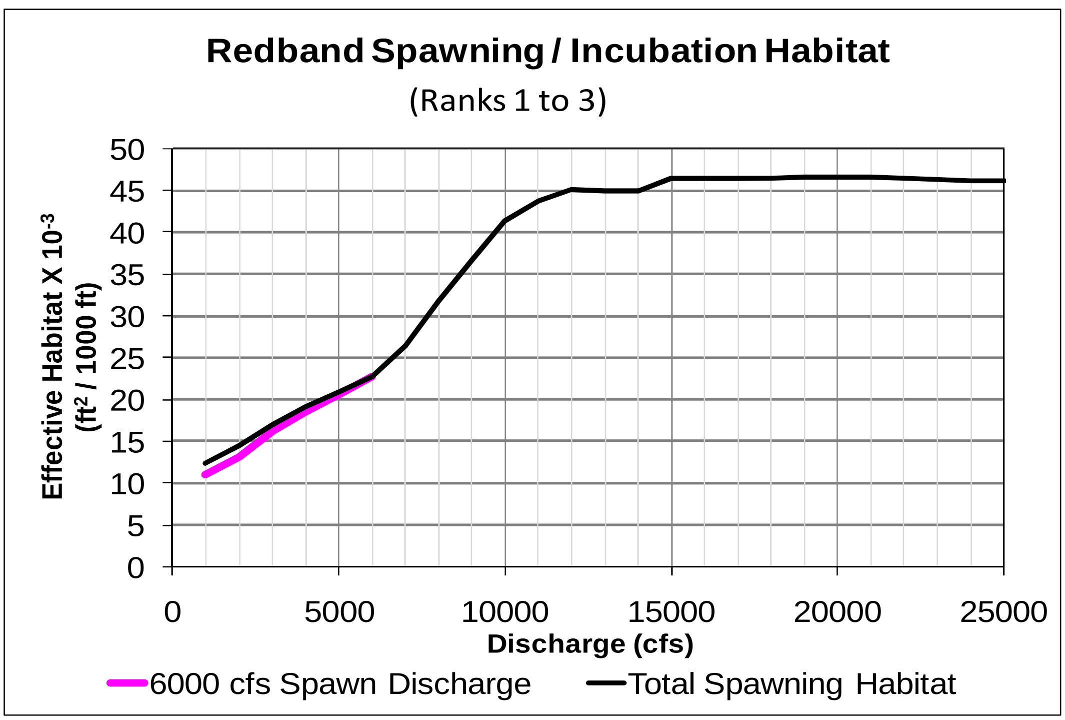
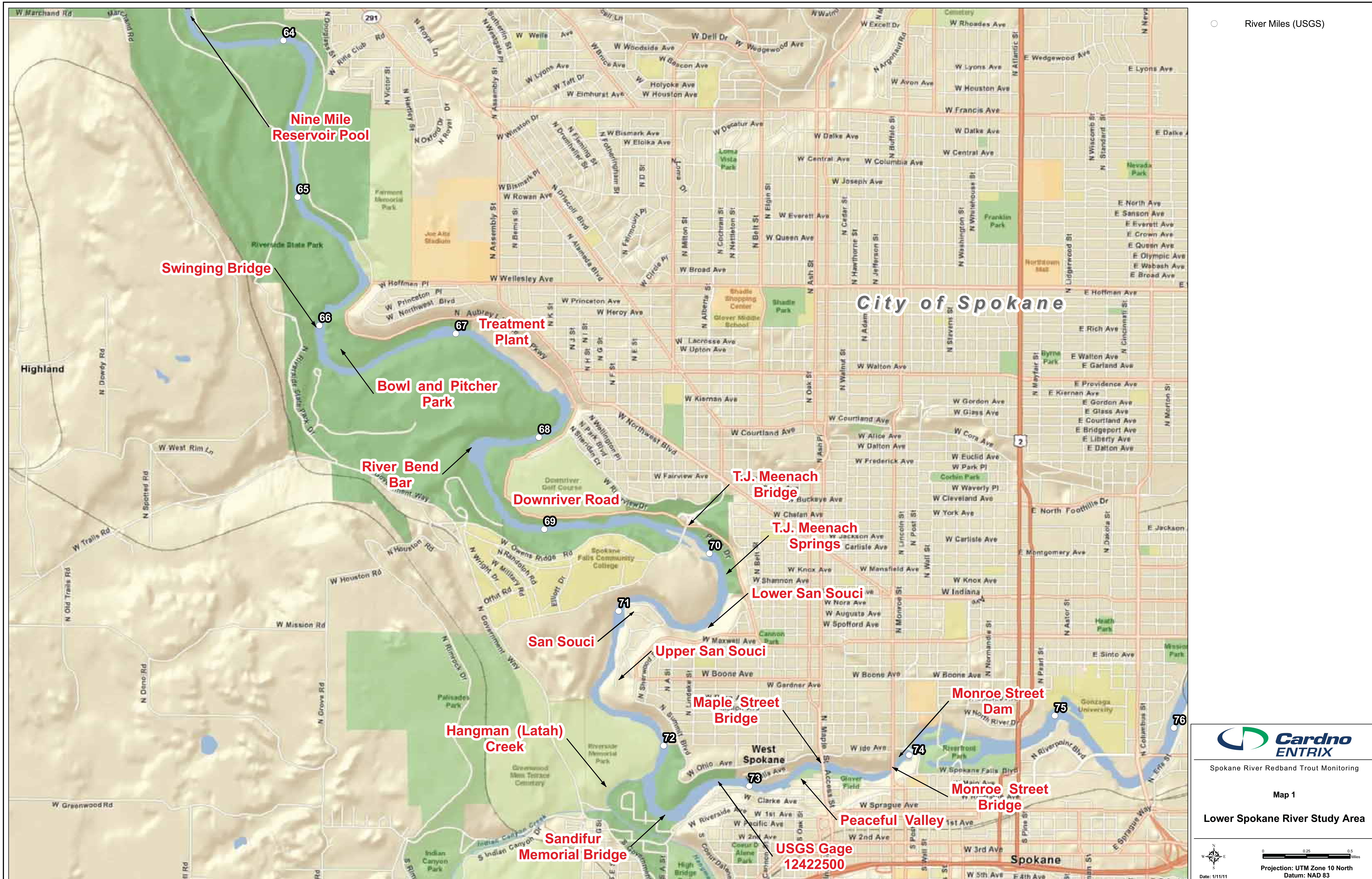


Figure 16. Total Spawning Habitat (black line) and the Effective Spawning Habitat (red line) at Initial Spawning Flows of 15,000 cfs (top) and 6,000 cfs (bottom) in Spawning Patches Ranked 1-3. Following the Effective Habitat Line (red) from Right to Left Shows the Amount of Spawning Habitat that Remains Effective at Different Minimum Flows during the Incubation Period.





MAPS



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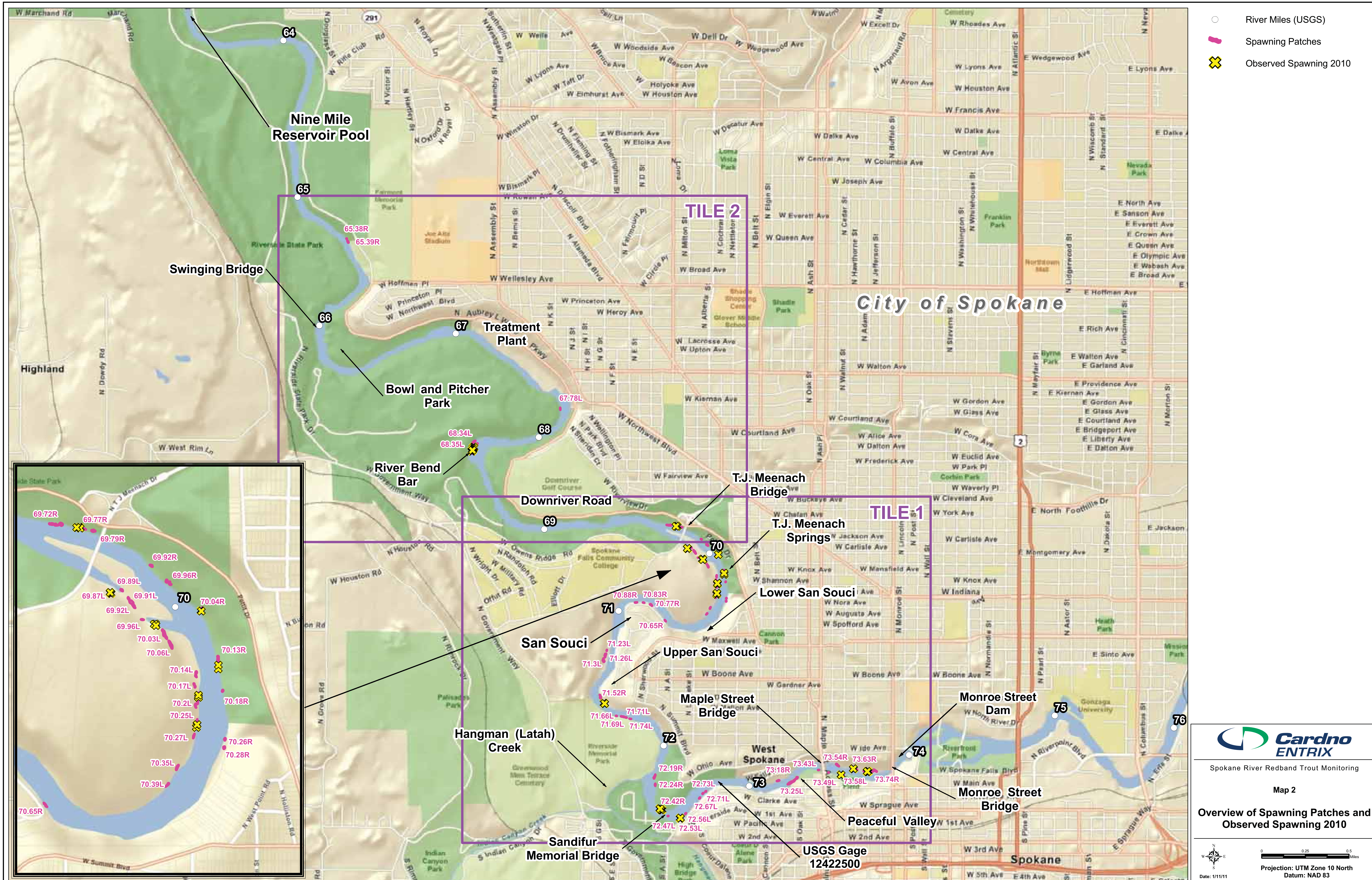

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River Miles (USGS)

Spawning Patches

Cardno ENTRIX

Spokane River Redband Trout Monitoring

Map 3

Spawning Patches

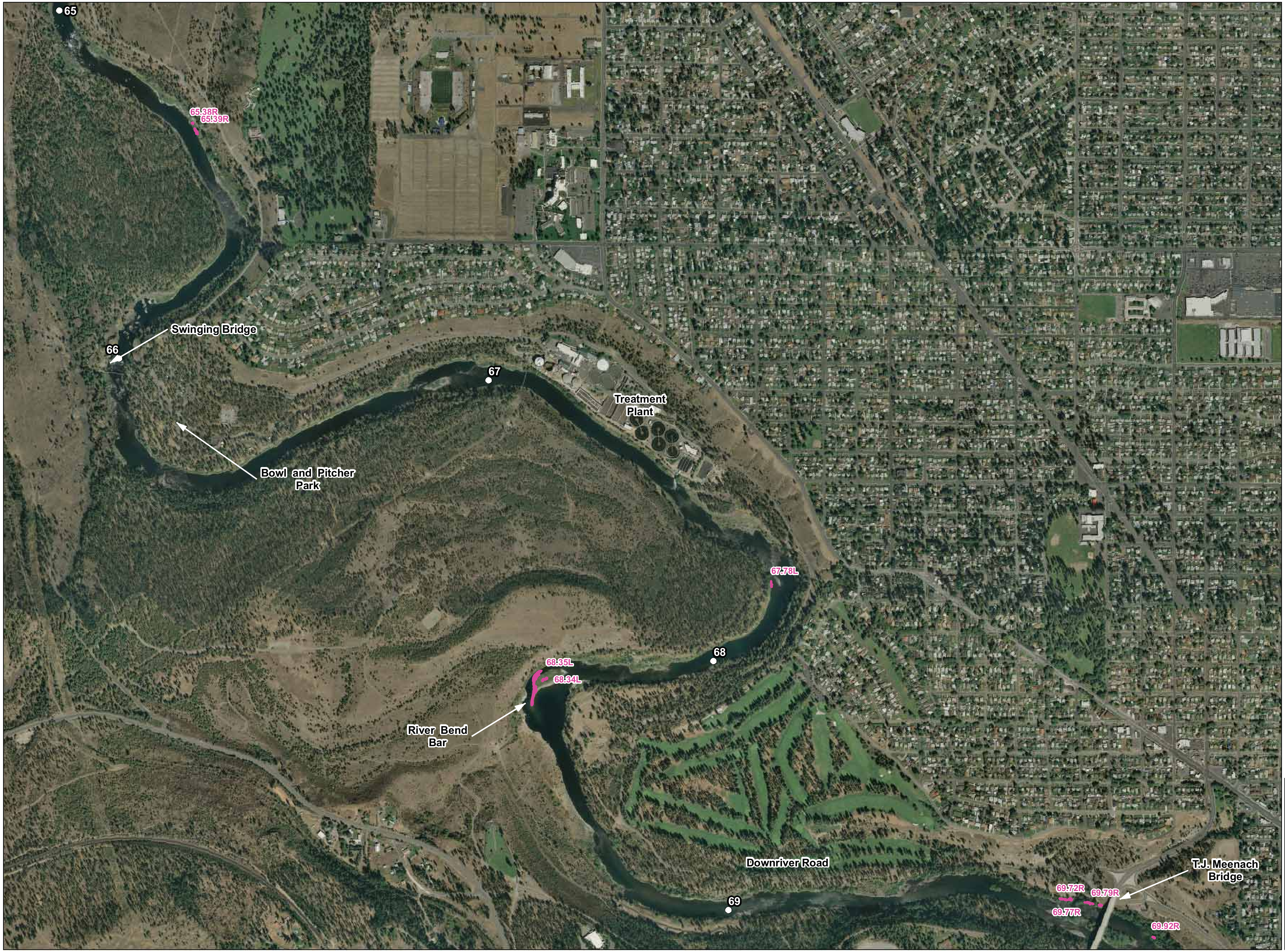
Tile 1

0 500 1,000 Feet

Projection: UTM Zone 10 North
Datum: NAD 83

Date: 1/11/11

Z:\GIS\Entrix\41036002_Avista\map\LowerSpokane_SpawningAreas_17i11i_01.mxd



River Miles (USGS)

Spawning Patches

Cardno ENTRIX

Spokane River Redband Trout Monitoring

Map 4

Spawning Patches

Tile 2

0 500 1,000 Feet

Date: 1/11/11

Projection: UTM Zone 10 North
Datum: NAD 83

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River Miles (USGS)

Spawning Patches

Observed Spawning 2010

Cardno ENTRIX

Spokane River Redband Trout Monitoring

Map 5

Observed Spawning 2010

Tile 1

0 500 1,000 Feet

Date: 1/11/11

Projection: UTM Zone 10 North
Datum: NAD 83

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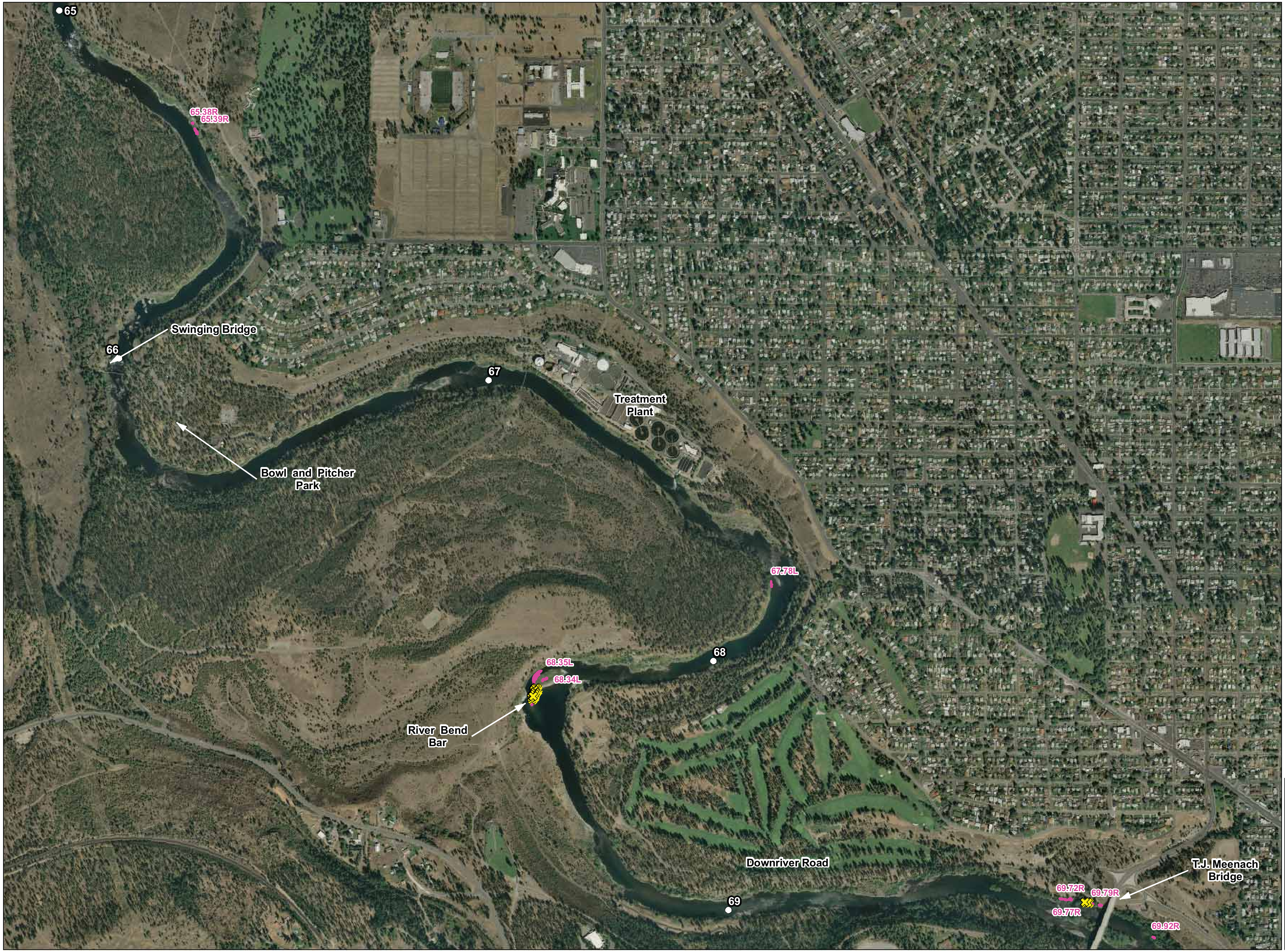

River Miles (USGS)
Spawning Patches
Observed Spawning 2010

Cardno ENTRIX

Spokane River Redband Trout Monitoring

Map 6

Observed Spawning 2010

Tile 2

Date: 1/11/11

0 500 1,000 Feet

Projection: UTM Zone 10 North
Datum: NAD 83

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APPENDIX A

Artificial Redd Methods

Page

1.0 GENERAL

Survival of many species of salmonids has been well studied from egg deposition in the redd environment through emergence of alevins into the stream using a wide range of approaches and methods (Harsbarger and Porter 1982, Sowden and Power 1985, Hoffman 1986, Garret and Bennett 1996, Argent and Flebbe 1999, Hendrick et. al. 2005, Zimmermann and LaPointe 2005, Radtke 2008). However, many of these methods are difficult to apply in a large river through a period of highly variable flow conditions due to the difficulty of installation and retrieval of sample devices as artificial redds, and the risk of potential loss of these devices. Careful consideration of experimental approaches and methods led us to use modified Whitlock-Vibert (W-V) boxes (Whitlock 1979) as the basic artificial redd unit coupled with the use of eyed triploid rainbow trout eggs. We used eyed triploid rainbow trout eggs to avoid stock transfer issues and because the egg size (approximately 5 mm diameter) was relatively close to that of redband trout. Because egg size strongly influences oxygen transfer to the developing eggs and alevin size, we assumed that the comparable size of the triploid rainbow trout eggs in our artificial redds should approximate similar rates of oxygen transfer and alevin size of that of redband trout. Based on this key condition we concluded that the response of the triploid eggs to the intragravel environment in spawning patches of the Spokane River would be similar to that of the native redband trout.

The experiment was a nested design, stratified at the highest level by a spawning patch quality strata (high, medium, and low quality) that was assigned based on factors including channel location and gravel composition. We installed three W-V boxes in each of three gravel patches in each of the three quality strata (27 W-V installations in total) and collected data for four independent variables (fines intruding into the W-V box, dissolved oxygen in the W-V box at two different times during incubation, water temperature, and dissolution rates of gypsum cylinders as surrogate for intragravel flow rate) against which survival at projected yolk sac absorption was compared.

2.0 W-V BOXES

We modified W-V boxes by removing the panel separating the egg chamber and the nursery chamber and affixing window screen to the inside of all box surfaces. The window screen openings were slightly larger than 1 x 1 mm. This modification was necessary to prevent the escape of alevins after hatching. Each box was filled with a core gravel mixture approximating the D_{50} particle size for the combined spawning gravel analysis (8-16 mm). Each box was also fitted with a ¼ inch diameter plastic tube that ran the length of the box and was fastened to the opposite end with a stainless steel screw threaded into the end of the tube from outside the box. The portion of the tube inside the W-V box was perforated to facilitate the withdrawal of a water sample from directly within the area of the developing eggs and alevins during the period of streambed burial.

After filling with gravel the boxes were shaken to shift gravels and fill voids within the boxes including around and under the water sampling tube (see image below).

Boxes were buried in the streambed within the patches approximately 3-5 feet apart and at a depth of 6-8 inches under the streambed surface to approximate the depth of redband trout egg pockets (DeVries 1997). Depressions were constructed in the streambed with a shovel and all boxes were buried on April 21 or 22, 2010. The boxes were held in place as they were covered with the excavated stream bed gravels. After burial was complete, the water sampling tube was filled with water, plugged and weighted down to the streambed by placing a rock on top of it. The rock kept the tube from floating in the current and made it less visible from the stream surface, a precaution against potential vandalism. All W-V boxes were retrieved on May 17 or 18 for determination of embryo survival.

3.0 EGG SOURCE

Triploid rainbow trout eggs were obtained from the Troutlodge Hatchery near Orting, WA and transported on ice to Spokane by vehicle the day preceding placement in the W-V boxes. At the time of placement into the W-V boxes the eggs were eyed and had a cumulative Celsius temperature unit value of 245, meaning they would hatch within approximately 8-10 days depending on the temperature environment of their exact location in the river. We projected the time to full yolk sac absorption based on assumed incubation temperatures and developmental rates obtained from Troutlodge to maximize exposure to intragravel conditions before retrieval. Planning for the retrieval of the W-V boxes balanced the desire to maximize their exposure to intragravel conditions with the risk of confining the alevins beyond the time when they would normally be emerging into the stream and the potential concomitant stress and mortality that might cause. W-V boxes were each allotted 50 eggs. Eggs were placed into the W-V boxes while the open boxes were partially submerged. The boxes were gently shaken to facilitate the settling of eggs into the interstices of the gravel matrix. After the eggs were placed in the boxes, the top of the gravel matrix was capped with slightly smaller gravels (approximately 4-8 mm average diameter) to approximate the cover gravels over an egg pocket and the box lid was snapped shut.

4.0 DISSOLVED OXYGEN

The plastic tubes connected to the W-V boxes were filled with water by gentle suction from a 100 ml syringe and plugged as the final step in W-V box installation. Two water samples were taken from the W-V boxes for field analysis of dissolved oxygen at 19 and 24 days following burial in the streambed, on May 10 or 11 and May 17 or 18 respectively. Sixty milliliter water samples were withdrawn for analysis after a volume of water equal to the tube volume, based on its inside diameter and total length to the W-V box (~17 ml), was withdrawn and discarded. Water was gradually withdrawn (~0.5 ml/sec) into the syringe to avoid pulling water into the incubation chamber from outside the artificial redd environment. Samples were immediately processed per instructions for field titration using a HACH Model OX-2P Dissolved Oxygen Test Kit.

5.0 GYPSUM CYLINDERS (CLOD CARDS)

Clod cards (Doty 1971, Petticrew and Kalff 1991, Leonetti 1997, Thompson and Glenn 1991, Porter et. al. 2000) were used to assess intragravel flow rates at the site of each W-V box. Clod cards were made of commercially available plaster of Paris (gypsum) poured into molds made from ABS pipe and had a 3/16 inch eye bolt placed in the center during production to provide an attachment point. Each cylinder measured 1.5 inches in diameter by 4 inches long and was oven dried for 48 hr at 105 degrees Fahrenheit and weighed to the nearest 0.1 gram. A clod card was inserted into the gravel approximately 12-18 inches lateral to each W-V box with a pipe and driver inserter prior egg box placement. Each clod card had a string attached to the eye bolt for retrieval that was allowed to trail over the streambed in the current. Upon retrieval of clod cards on May 10 or 11 (19-20 days post installation), they were dried as above and reweighed to determine the mass loss during the period of deployment.

6.0 TEMPERATURE

We attached a temperature data logger (Onset Tidbit brand) to one box in each patch to record intragravel temperatures. We assumed that the temperatures recorded for the one box would be representative of temperatures for the other two boxes in the patch. Surface water temperatures were recorded upstream from the Spokane City wastewater treatment plant.

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APPENDIX B

Spawning Patch Maps, Photographs, and Redd Locations

(See Attached Electronic File)

APPENDIX C

Gravel Composition

List of Figures

Figure C-1. Patch 65.38R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	98.5	1.5	51
16	63.0	35.6	1250
8	41.6	21.4	752
4	35.2	6.4	224
2	32.8	2.4	84
1	31.7	1.2	42
0.5	29.4	2.2	78
0.25	17.2	12.3	431
Pan	---	17.2	604
Total			3516

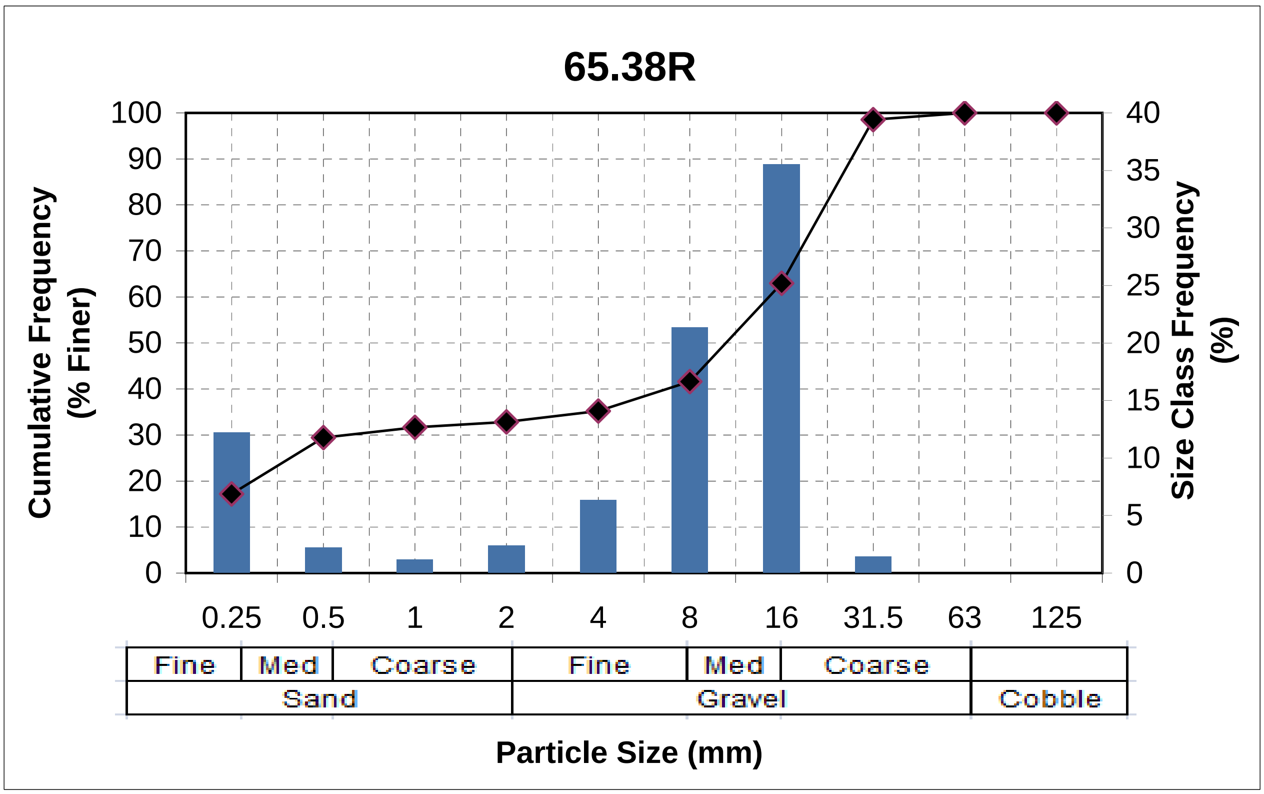


Figure C-2. Patch 65.39R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	88.7	11.3	441
16	60.1	28.6	1121
8	43.0	17.1	668
4	32.0	11.0	431
2	25.8	6.2	242
1	23.3	2.5	99
0.5	20.2	3.1	123
0.25	8.8	11.4	446
Pan	---	8.8	343
Total			3914

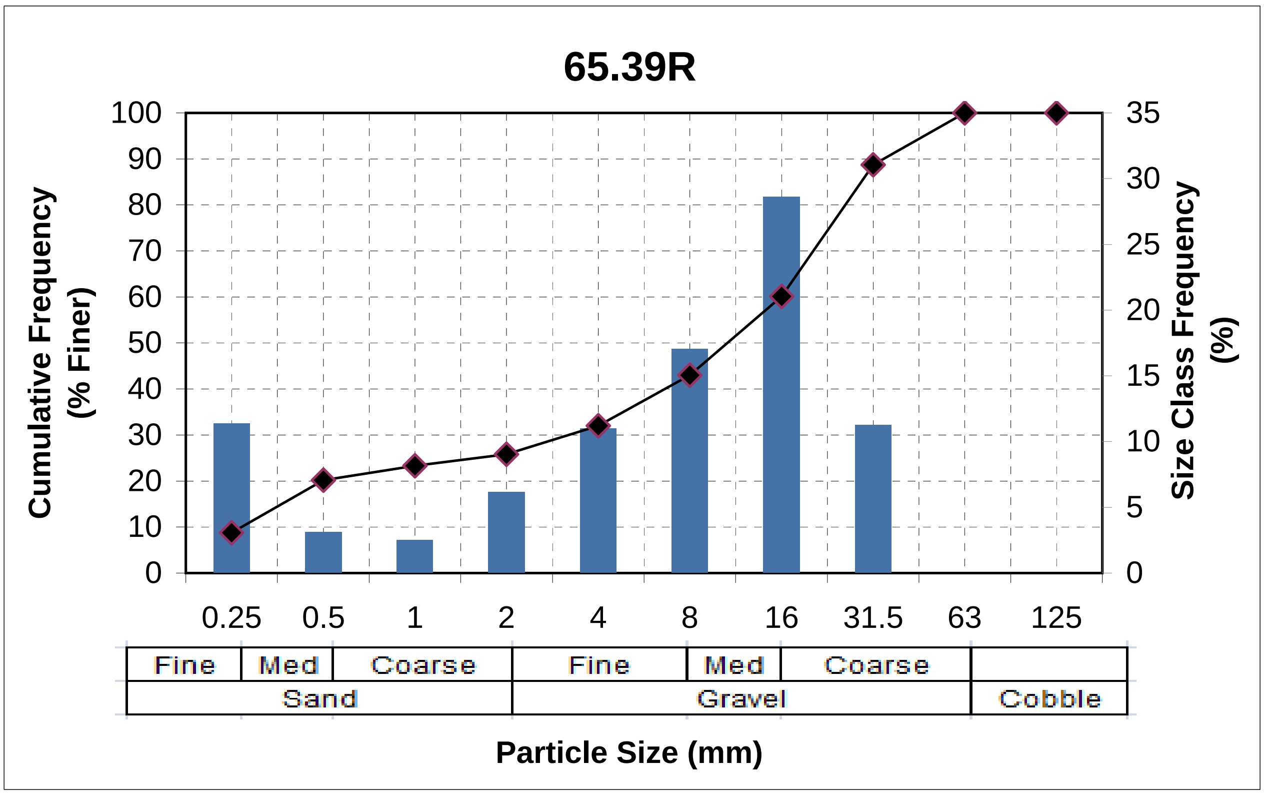


Figure C-3. Patch 67.78L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	60.5	39.5	1364
16	46.9	13.6	469
8	38.5	8.4	288
4	32.6	5.9	202
2	22.3	10.4	358
1	8.6	13.7	471
0.5	1.2	7.5	257
0.25	0.2	0.9	32
Pan	---	0.2	8
Total			3449

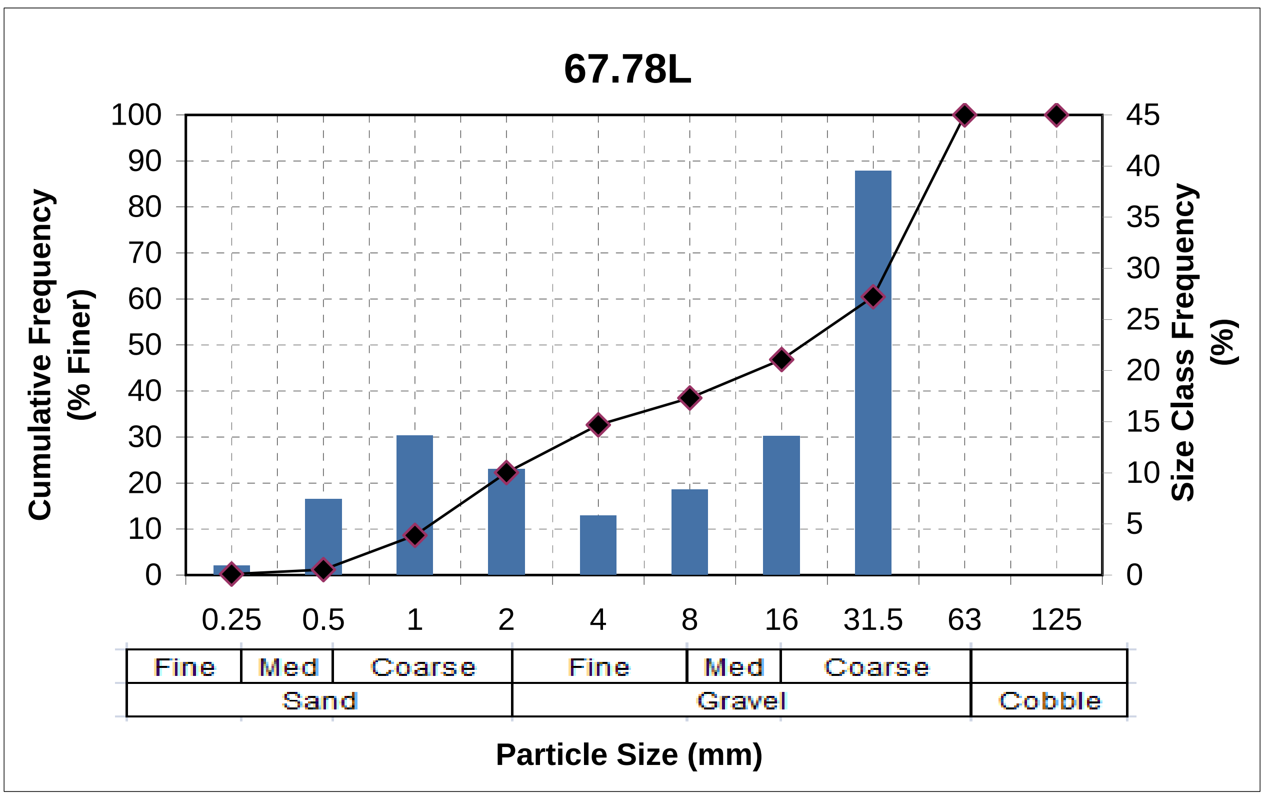


Figure C-4. Patch 68.34L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	81.1	18.9	989
31.5	59.2	21.8	1142
16	49.3	9.9	519
8	43.0	6.3	329
4	38.3	4.7	247
2	27.3	11.0	575
1	12.6	14.7	769
0.5	4.2	8.4	440
0.25	0.9	3.3	174
Pan	---	0.9	45
Total			5229

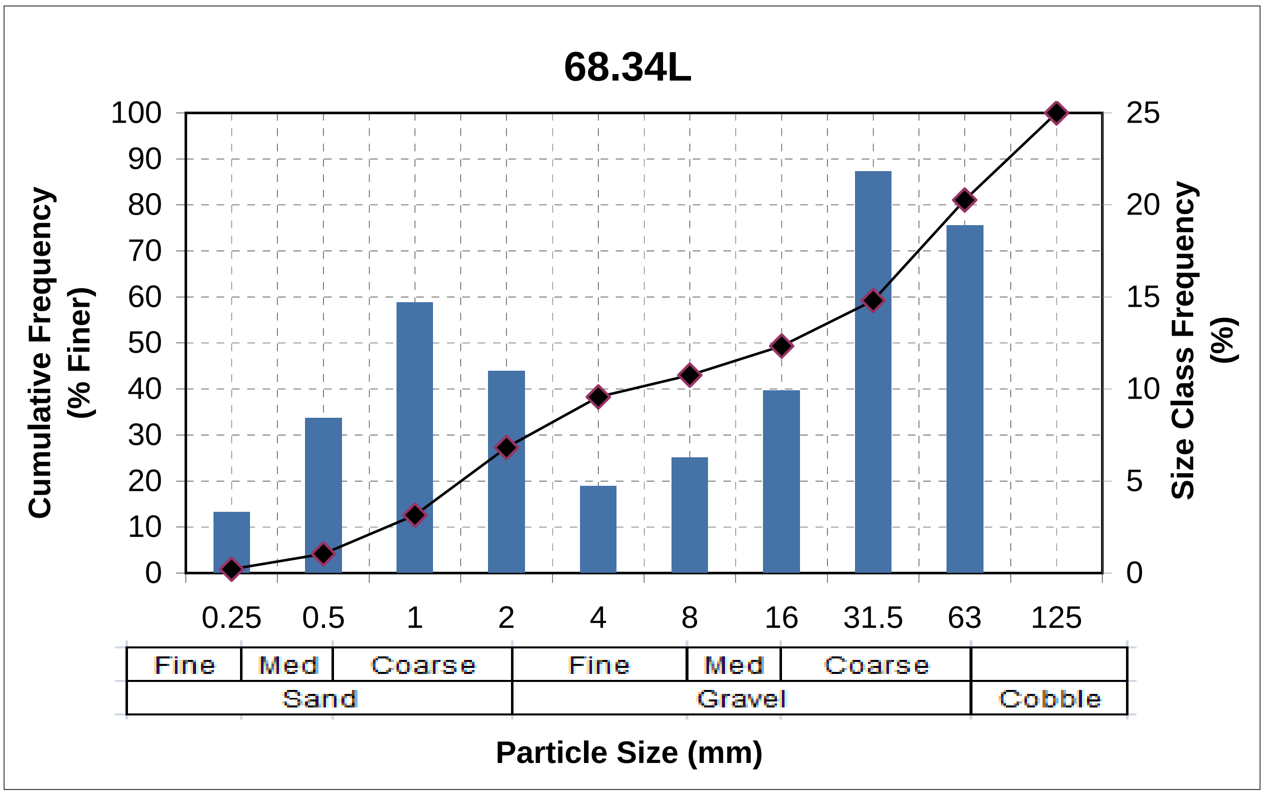


Figure C-5. Patch 68.35L Gravel Size and Percentage (n=6).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	92.0	8.0	1951
16	69.5	22.5	5460
8	55.9	13.5	3284
4	46.6	9.3	2260
2	36.9	9.7	2365
1	21.8	15.0	3652
0.5	6.4	15.5	3750
0.25	1.1	5.3	1277
Pan	---	1.1	267
Total			24266

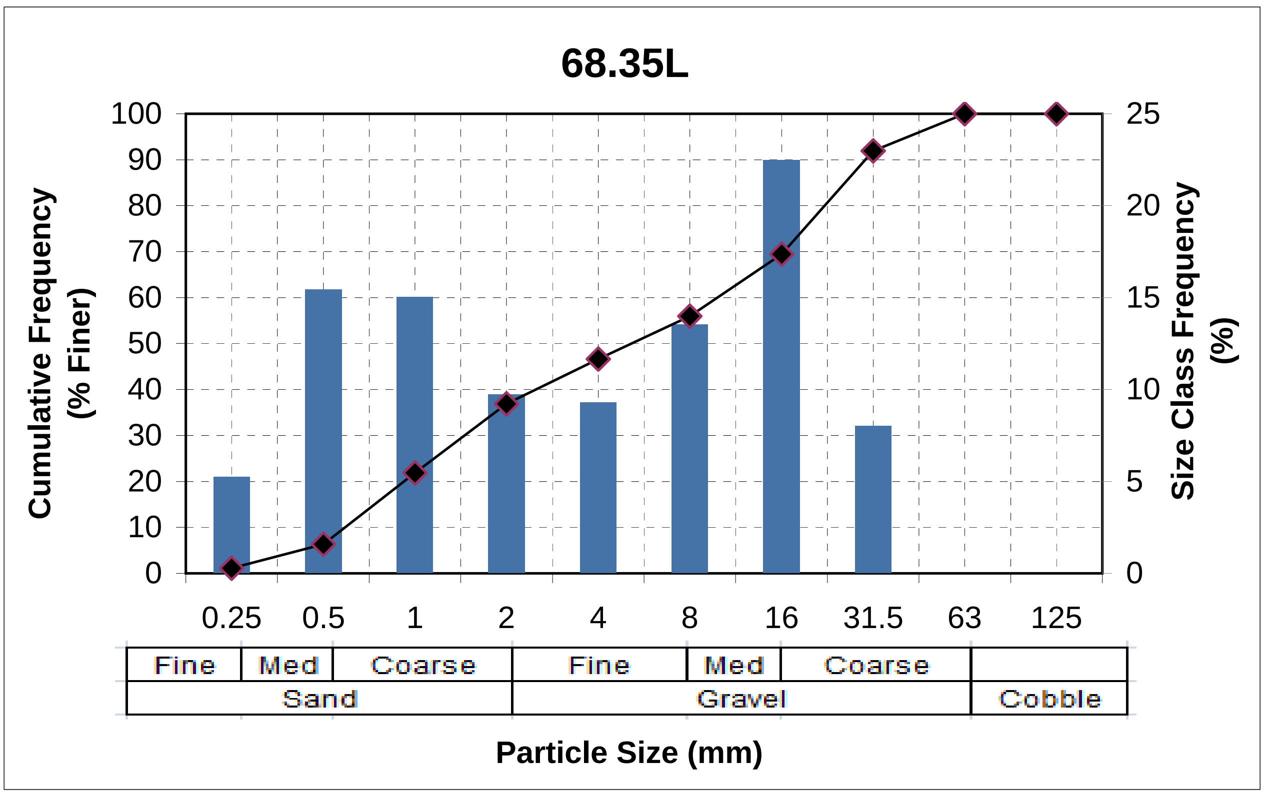


Figure C-6. Patch 69.72R Gravel Size and Percentage (n=3).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	90.7	9.3	1136
16	65.9	24.8	3034
8	45.5	20.4	2487
4	32.3	13.2	1613
2	19.9	12.4	1516
1	9.6	10.3	1256
0.5	4.7	5.0	605
0.25	2.0	2.7	326
Pan	---	2.0	243
Total			12216

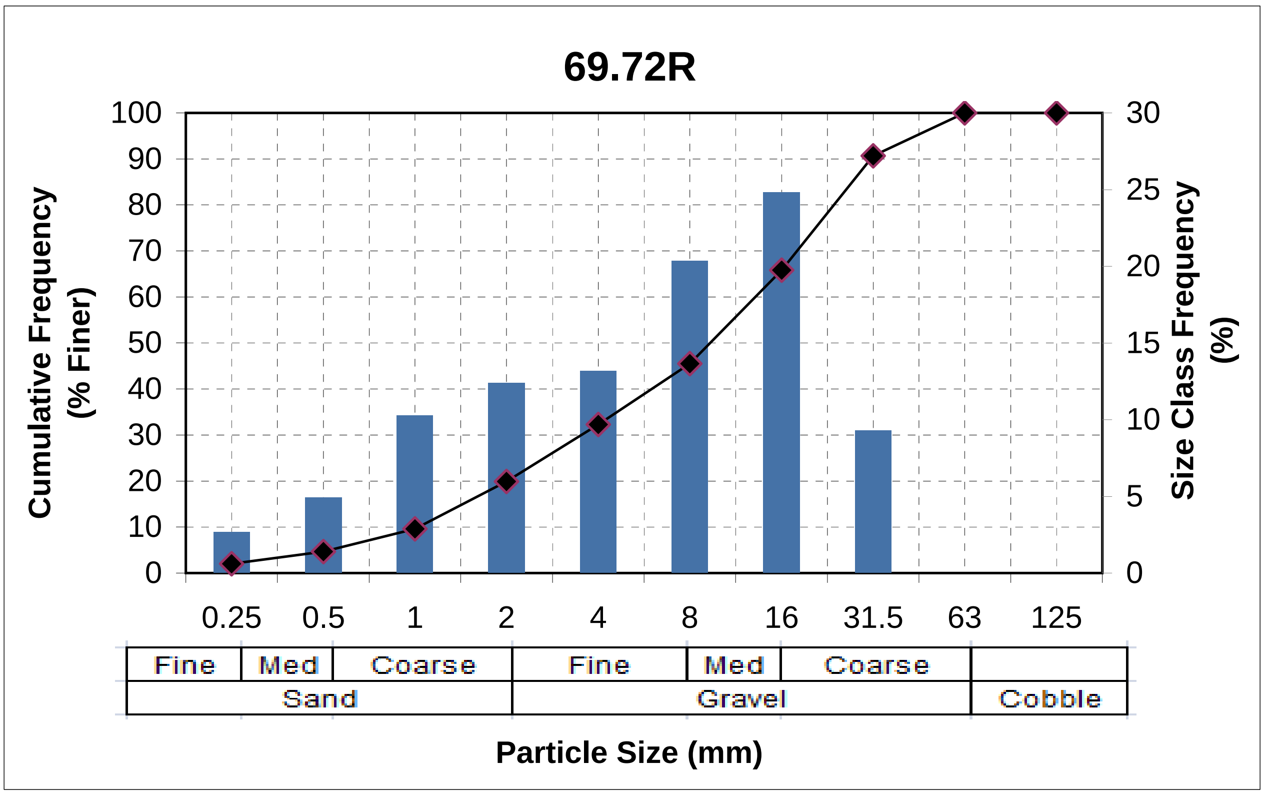


Figure C-7. Patch 69.77R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	88.5	11.5	485
16	71.5	17.0	720
8	50.3	21.2	895
4	32.8	17.6	742
2	20.4	12.3	522
1	11.7	8.8	370
0.5	5.3	6.4	270
0.25	2.5	2.7	116
Pan	---	2.5	107
Total			4227

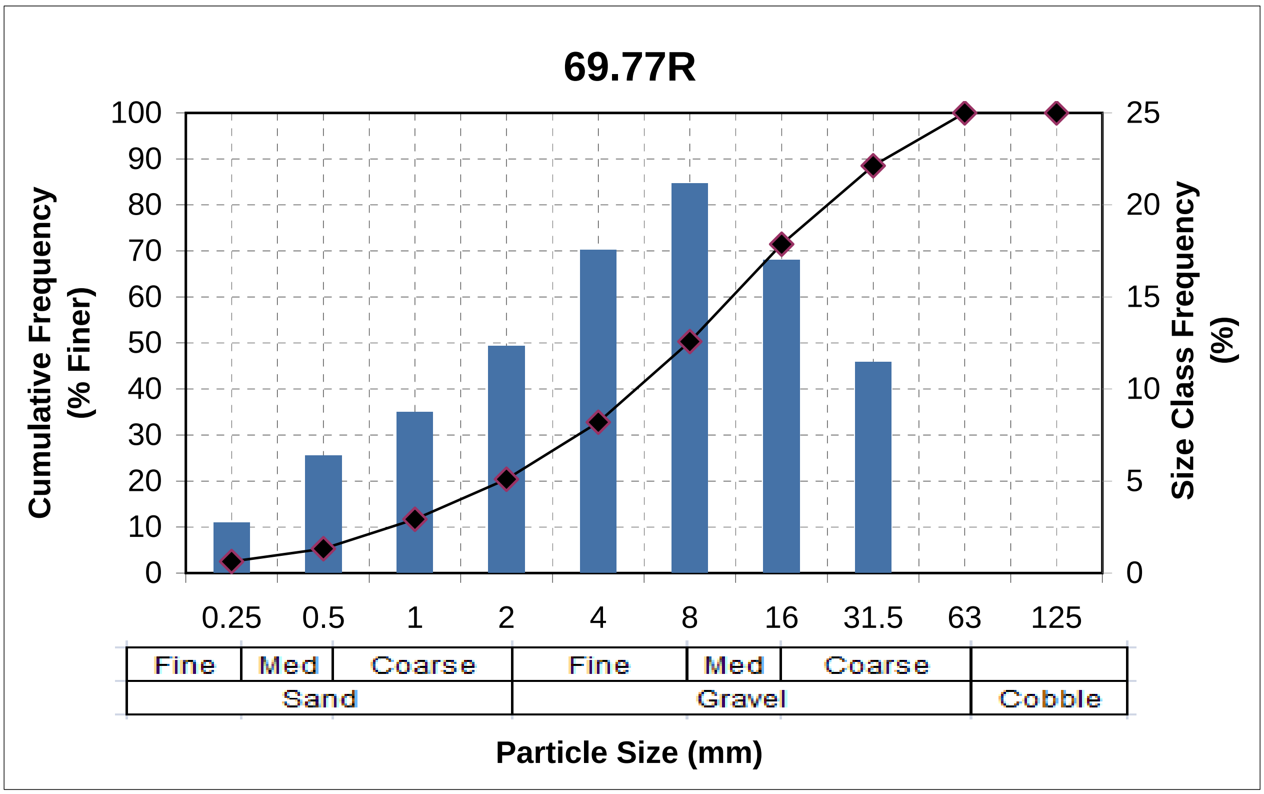


Figure C-8. Patch 69.79R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	88.7	11.3	440
16	70.9	17.8	694
8	59.6	11.3	439
4	47.4	12.2	475
2	37.9	9.6	373
1	24.4	13.4	524
0.5	11.3	13.1	510
0.25	6.7	4.6	179
Pan	---	6.7	262
Total			3896

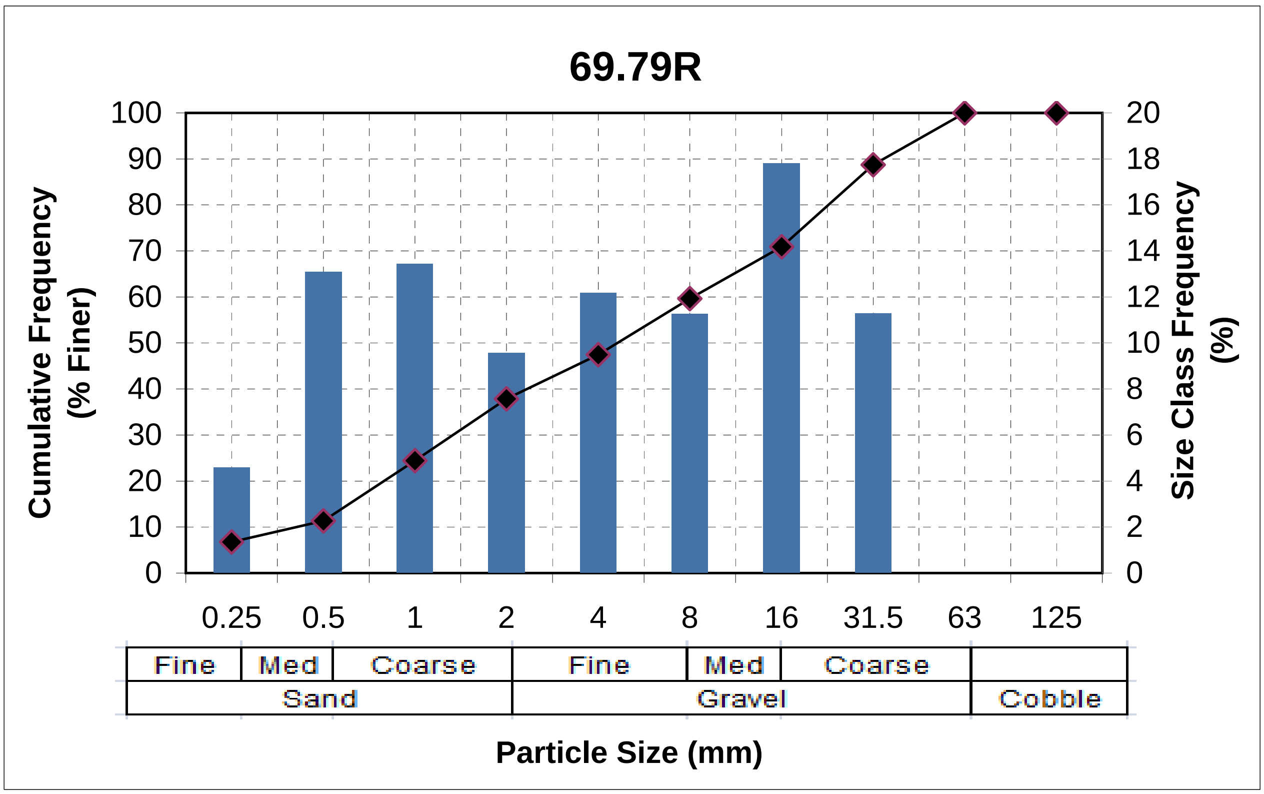


Figure C-9. Patch 69.87L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	90.2	9.8	445
16	57.3	33.0	1500
8	31.1	26.1	1190
4	22.1	9.0	410
2	18.7	3.4	154
1	16.6	2.1	97
0.5	8.4	8.2	375
0.25	1.9	6.5	296
Pan	---	1.9	85
Total			4552

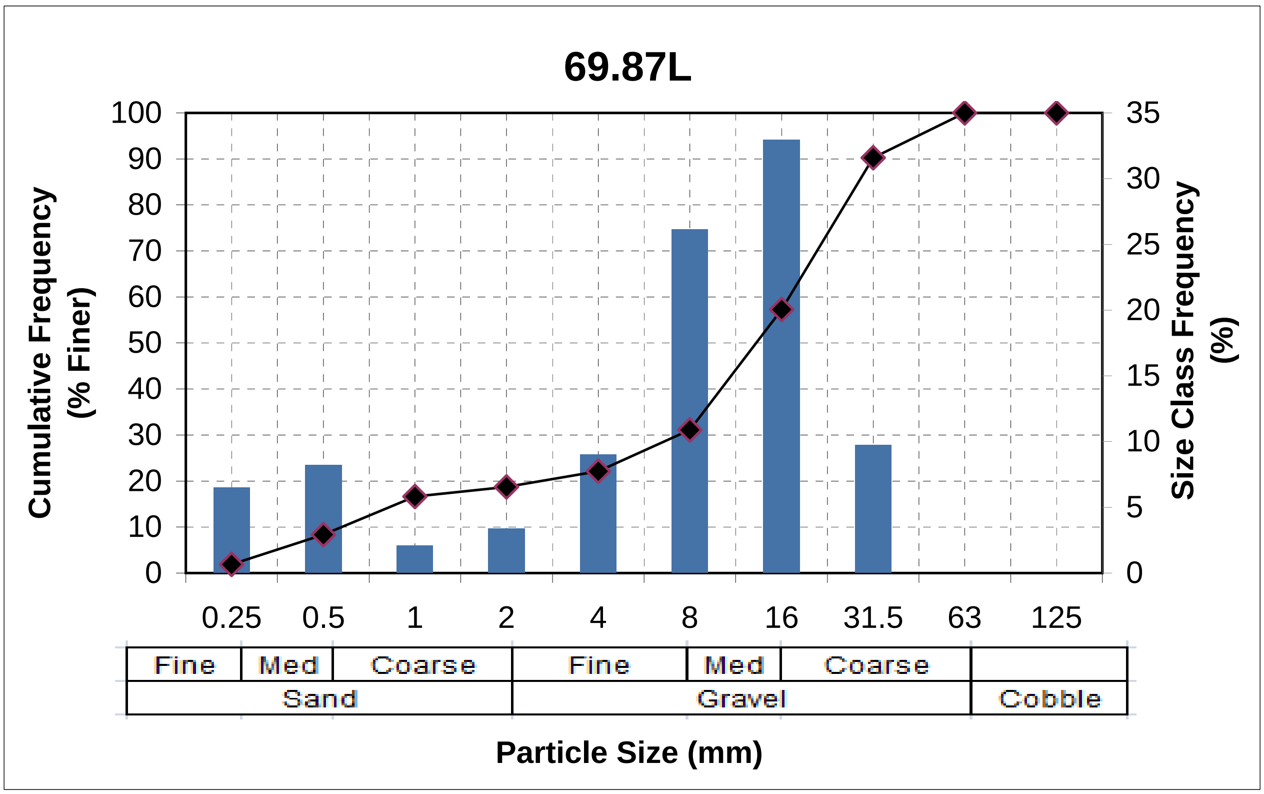


Figure C-10. Patch 69.89L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	92.1	7.9	350
16	64.1	28.0	1240
8	42.3	21.7	960
4	32.1	10.3	455
2	21.0	11.1	490
1	8.3	12.7	563
0.5	0.8	7.5	331
0.25	0.1	0.7	31
Pan	---	0.1	3
Total			4423

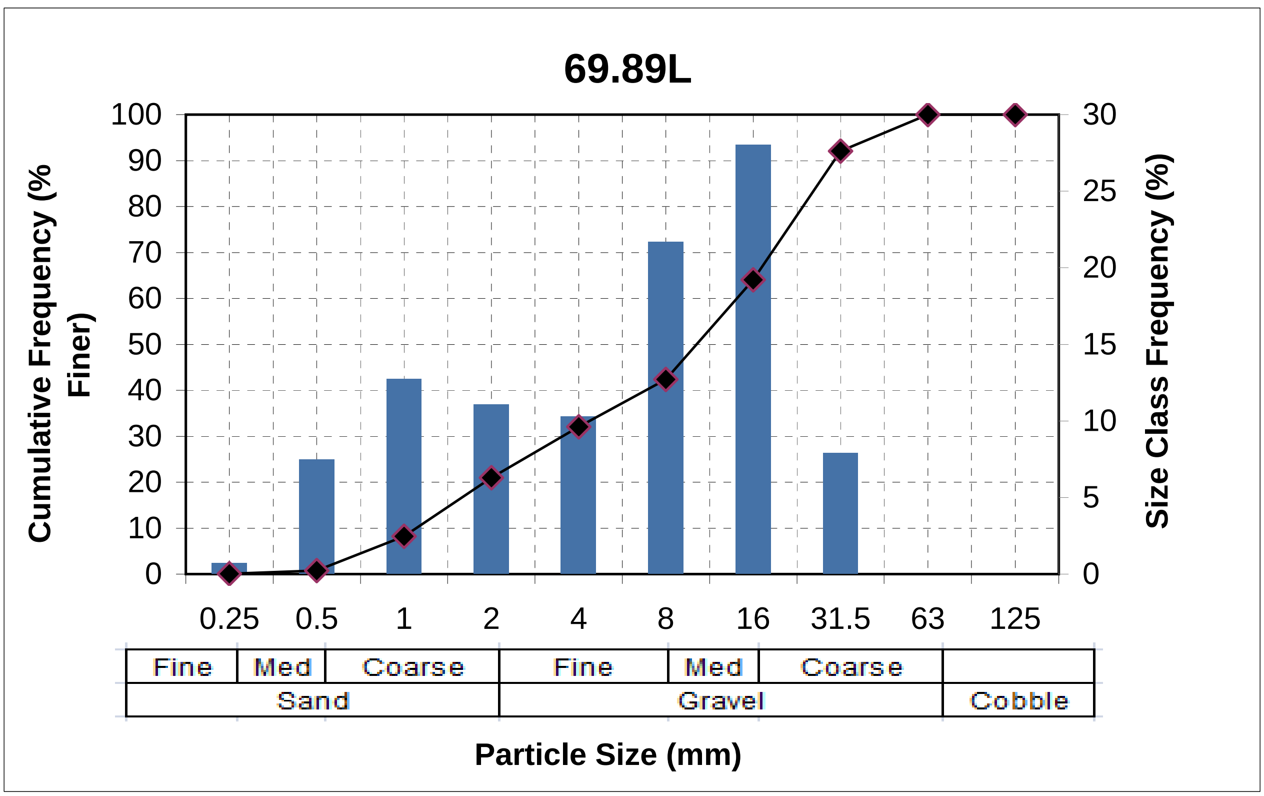


Figure C-11. Patch 69.91L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	96.0	4.0	127
16	74.1	21.8	685
8	50.9	23.2	729
4	36.2	14.7	461
2	20.8	15.4	482
1	10.6	10.2	321
0.5	4.2	6.4	201
0.25	1.0	3.2	99
Pan	---	1.0	32
Total			3137

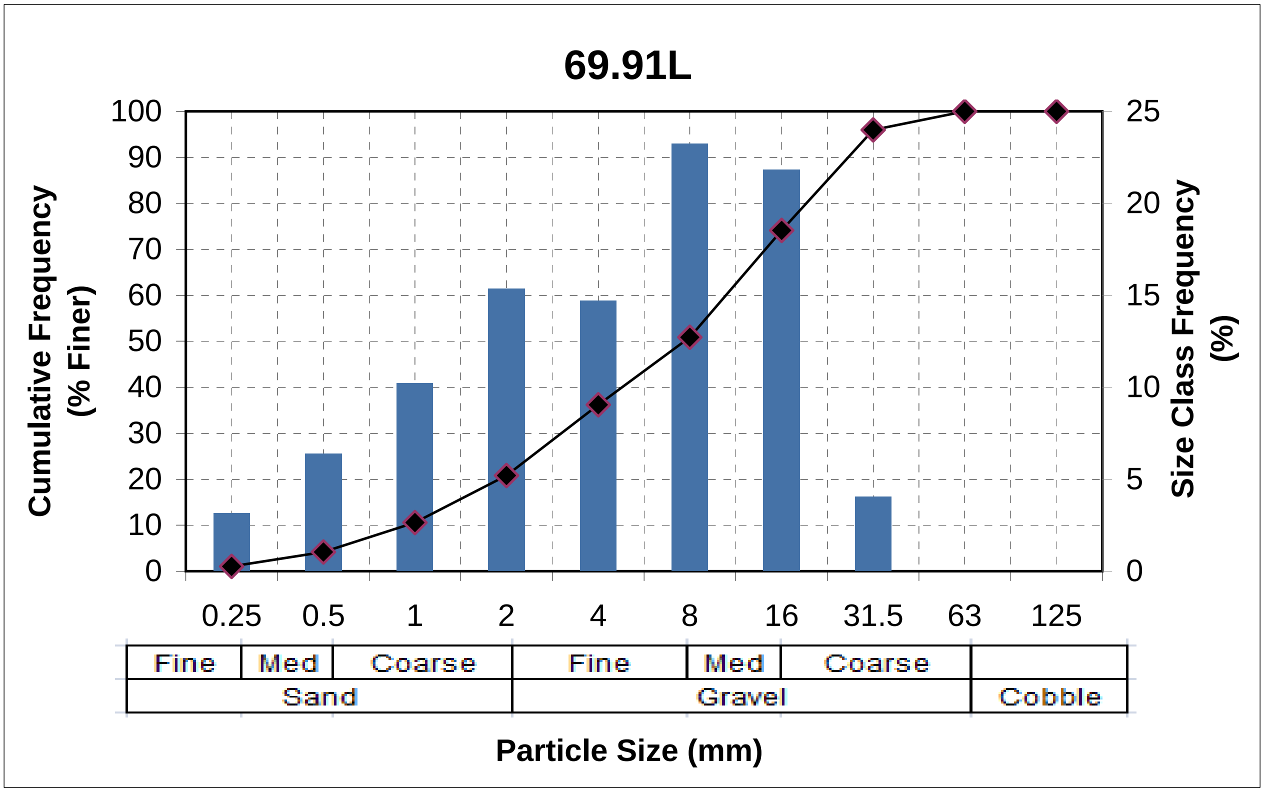


Figure C-12. Patch 69.92R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	83.8	16.2	580
16	66.5	17.3	617
8	51.7	14.8	528
4	41.6	10.1	362
2	27.5	14.2	506
1	19.6	7.9	281
0.5	16.3	3.3	119
0.25	8.9	7.4	263
Pan	---	8.9	319

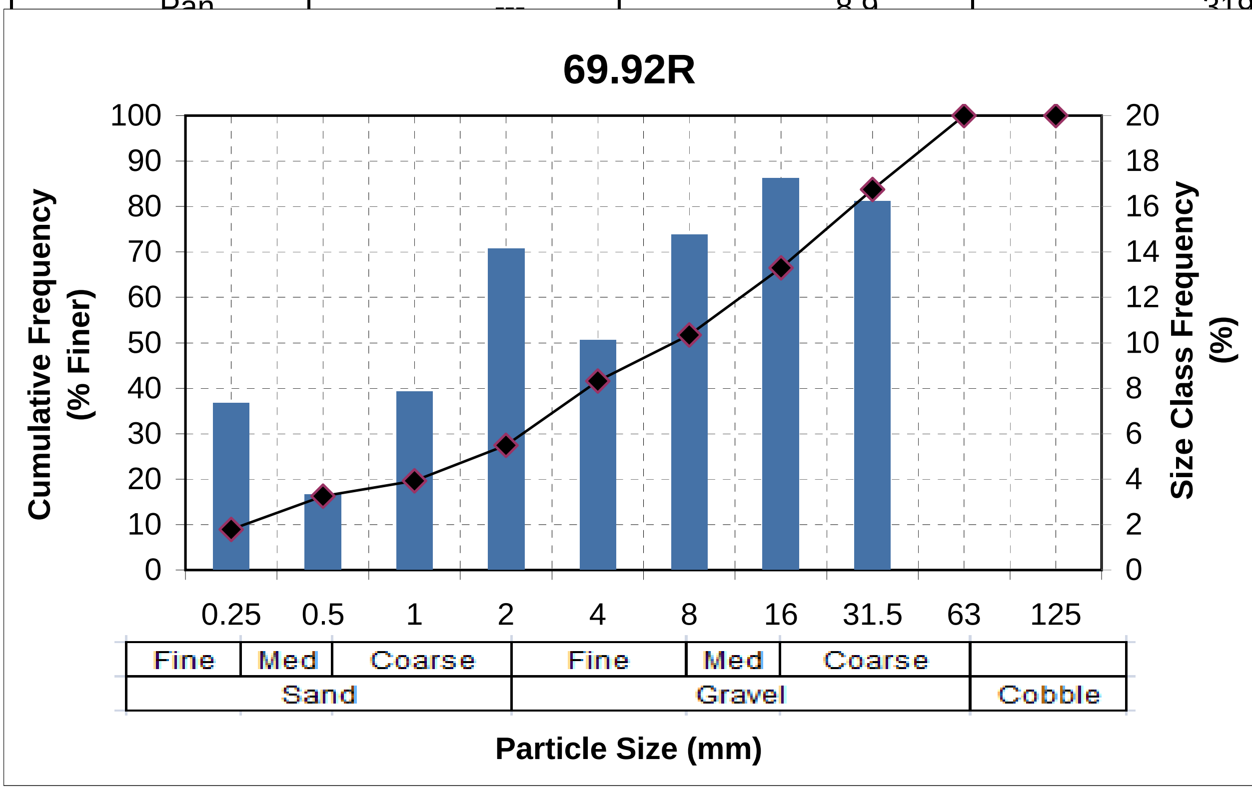


Figure C-13. Patch 69.92L Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	97.3	2.7	191
16	71.8	25.4	1783
8	52.5	19.3	1356
4	41.7	10.8	759
2	29.5	12.2	857
1	20.4	9.1	636
0.5	10.2	10.2	715
0.25	2.4	7.8	549
Pan	---	2.4	165
Total			7011

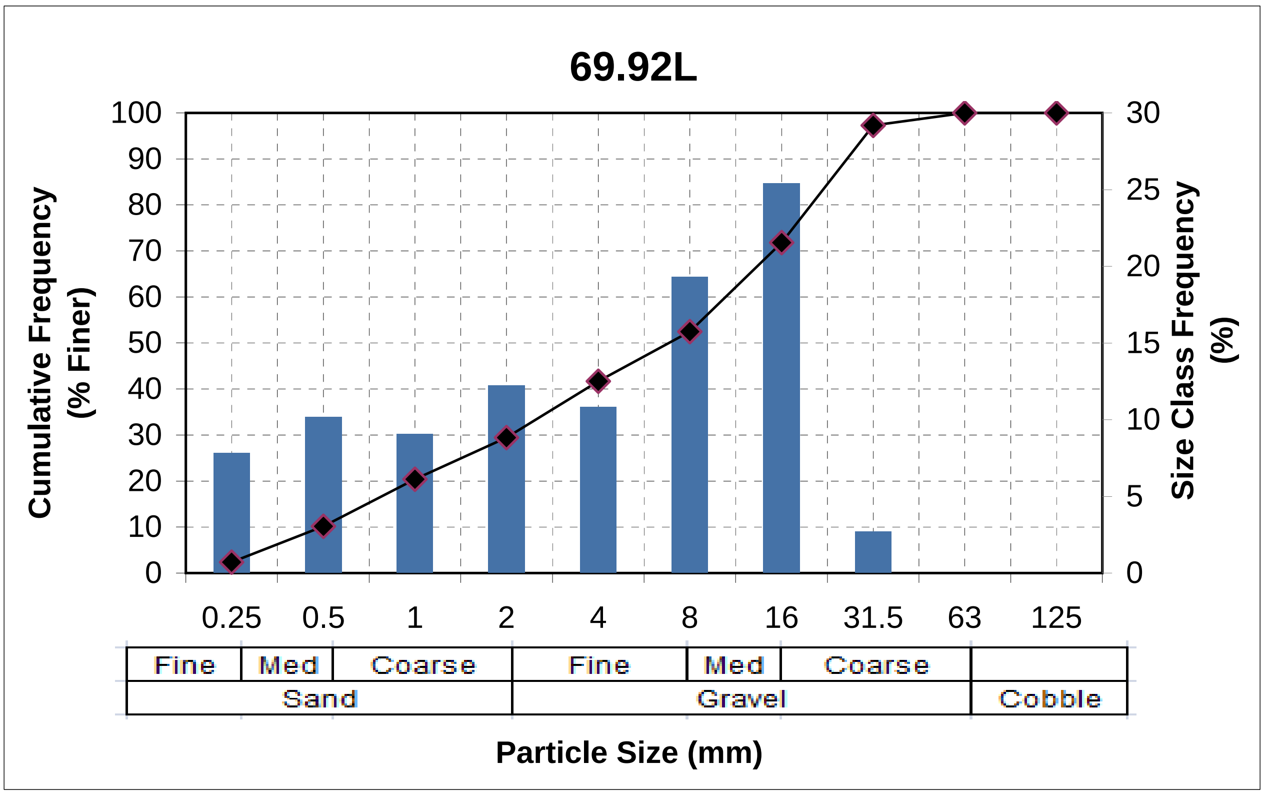


Figure C-14. Patch 69.96R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	100.0	0.0	0
16	87.7	12.3	575
8	60.9	26.8	1250
4	41.2	19.7	920
2	24.9	16.3	759
1	12.6	12.3	572
0.5	5.8	6.9	320
0.25	2.3	3.5	163
Pan	---	2.3	106
Total			4665

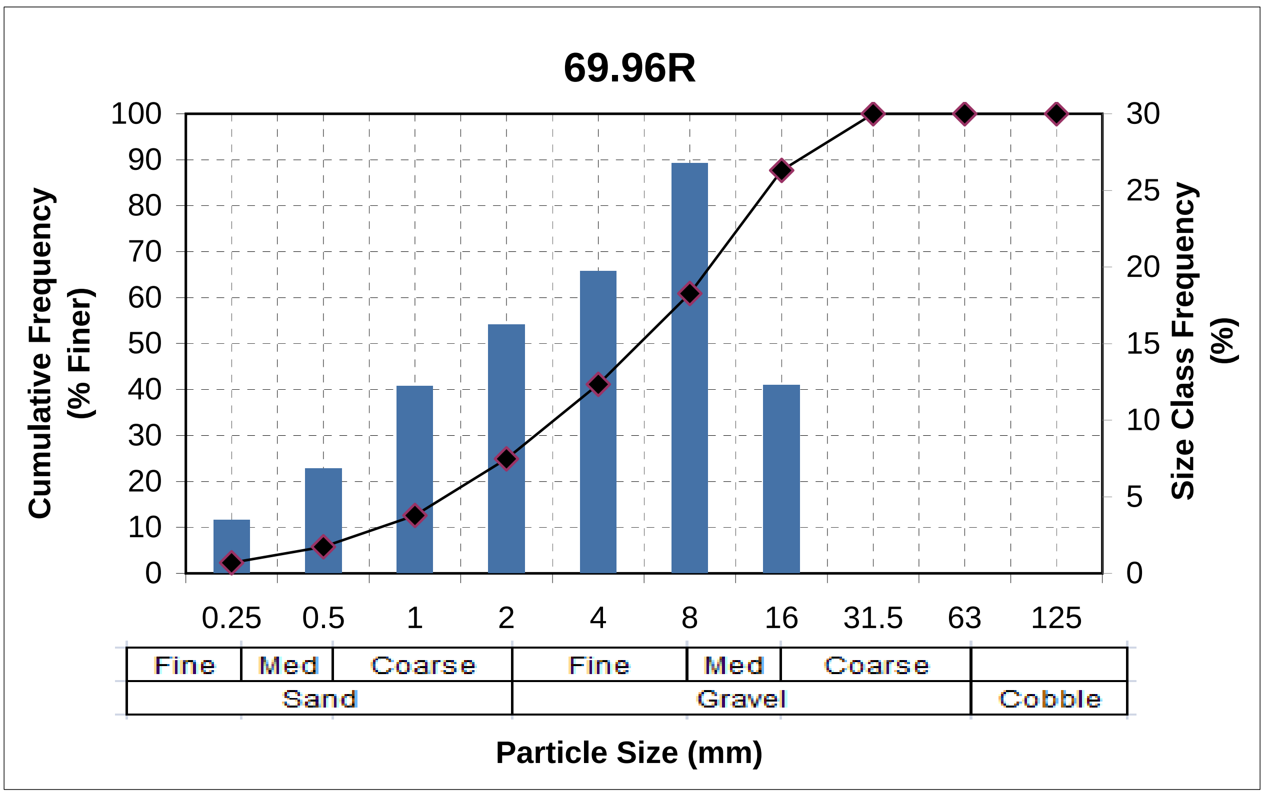


Figure C-15. Patch 69.96L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	89.7	10.3	435
31.5	57.1	32.6	1370
16	21.9	35.2	1480
8	14.1	7.9	331
4	10.0	4.1	173
2	5.6	4.3	183
1	2.7	2.9	124
0.5	1.4	1.3	53
0.25	0.3	1.1	48
Pan	---	0.3	11
Total			4208

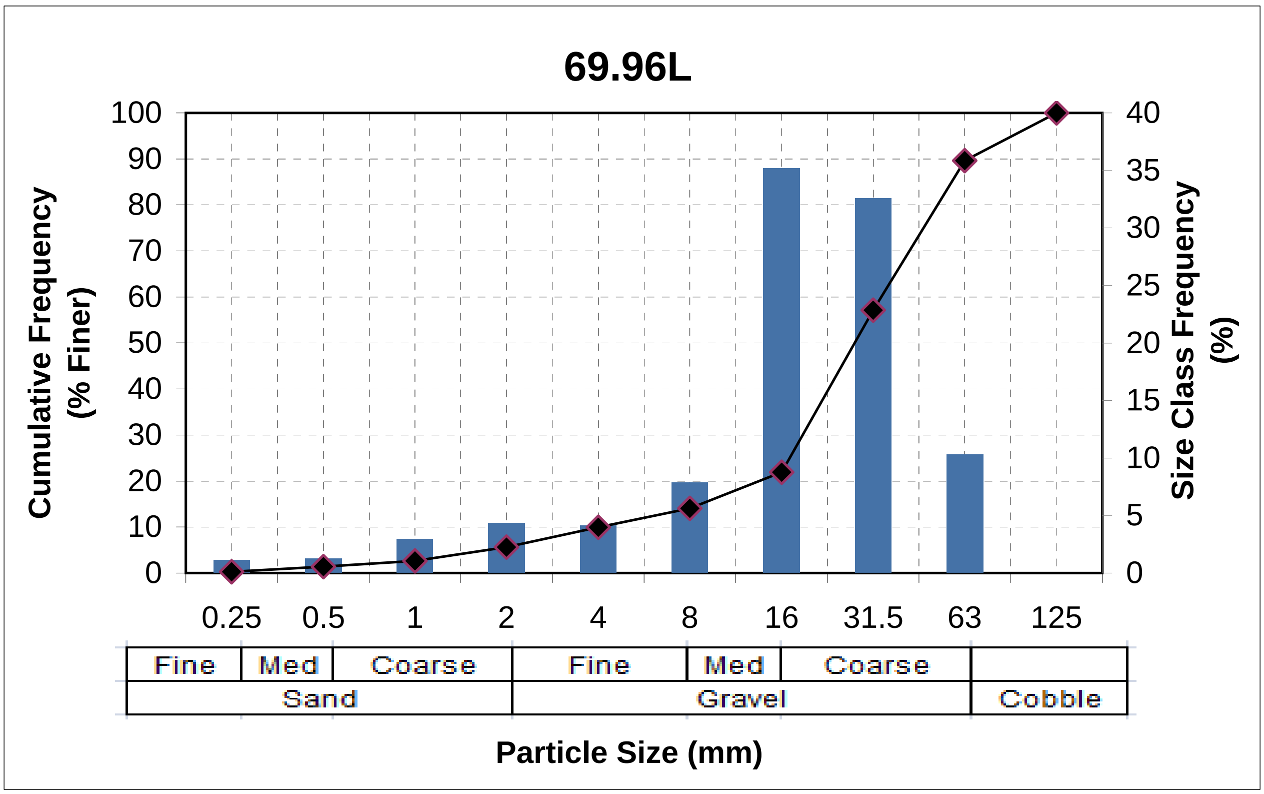


Figure C-16. Patch 70.03L Gravel Size and Percentage (n=3).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	83.9	16.1	2091
16	60.1	23.8	3091
8	46.5	13.6	1765
4	37.6	8.9	1156
2	29.9	7.6	988
1	19.4	10.6	1371
0.5	5.7	13.7	1778
0.25	1.0	4.7	604
Pan	---	1.0	133
Total			12977

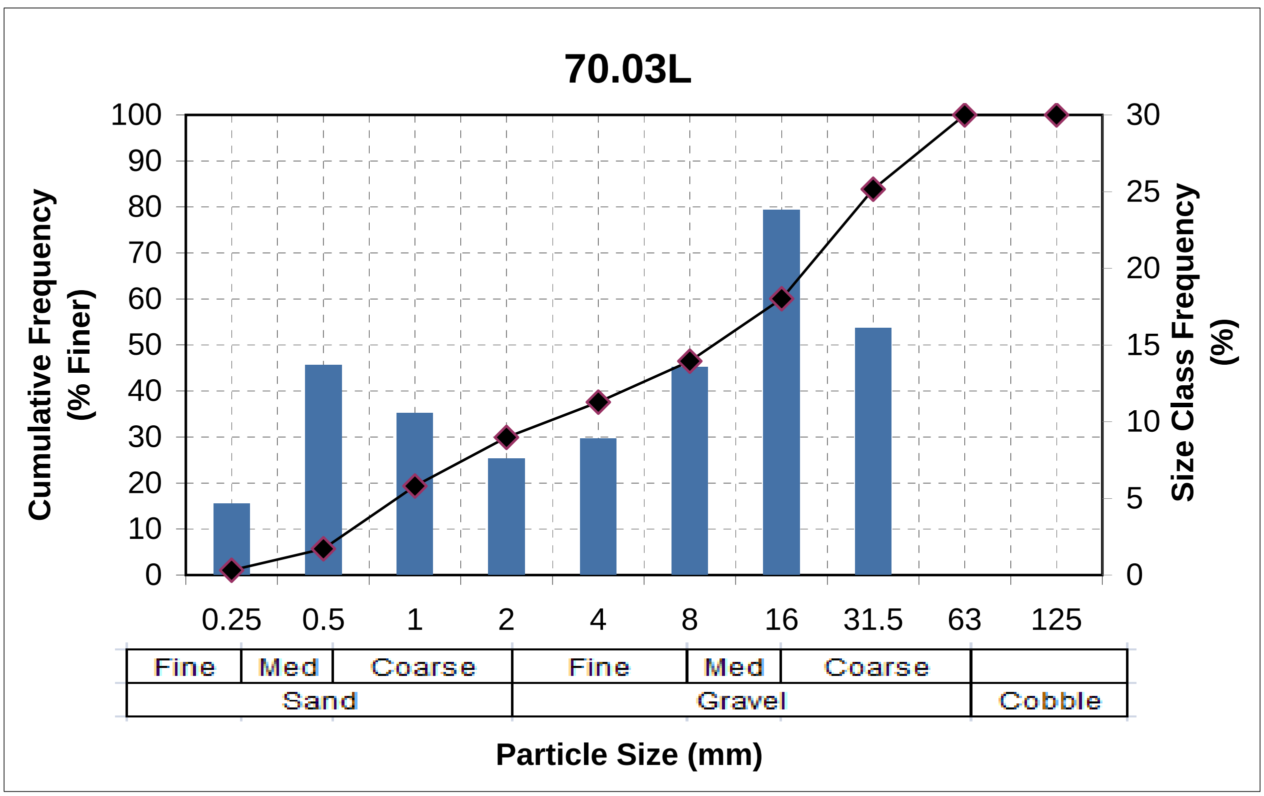


Figure C-17. Patch 70.04R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	86.8	13.2	592
16	63.2	23.7	1063
8	42.4	20.7	931
4	30.8	11.6	522
2	23.2	7.7	344
1	16.4	6.8	304
0.5	8.8	7.6	341
0.25	2.3	6.5	293
Pan	---	2.3	102
Total			4492

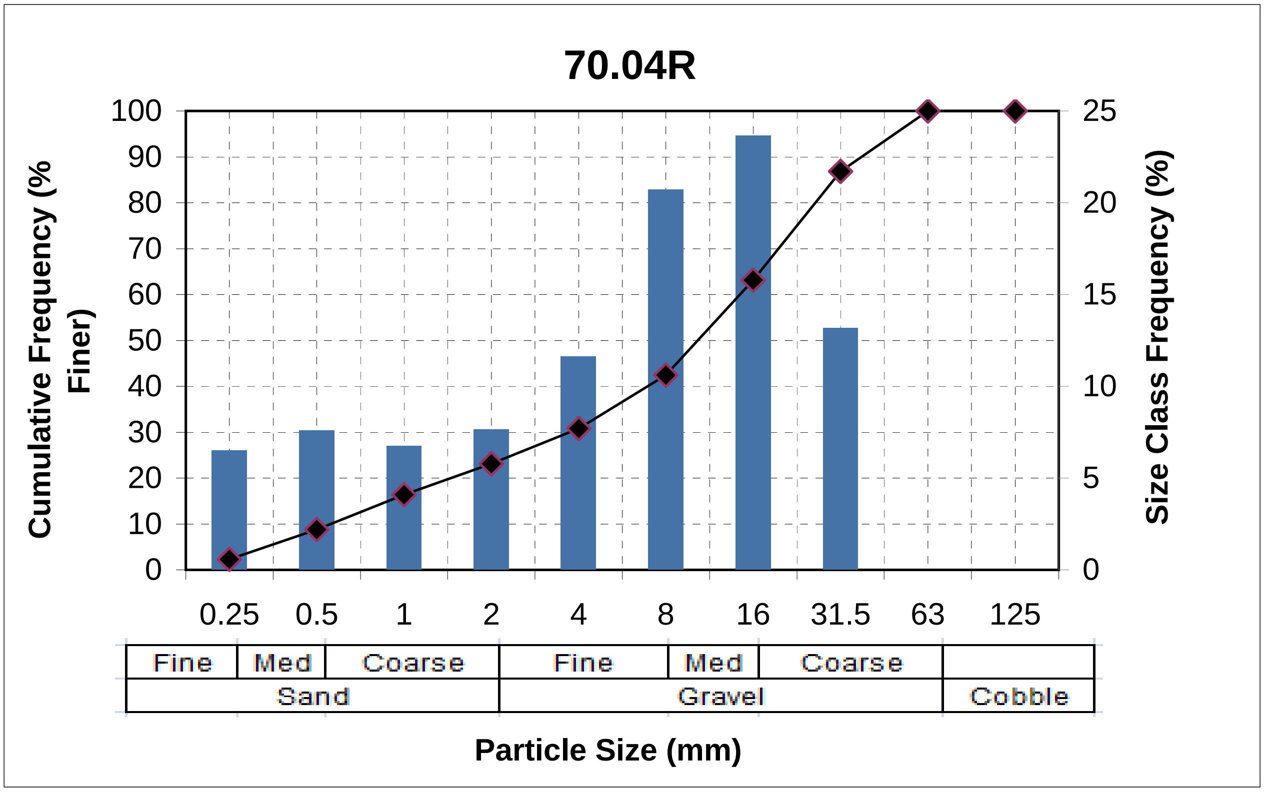


Figure C-18. Patch 70.06L Gravel Size and Percentage (n=3).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	79.8	20.2	3383
16	64.1	15.7	2635
8	49.2	14.9	2502
4	38.4	10.8	1813
2	26.9	11.5	1930
1	15.0	11.9	1998
0.5	4.6	10.4	1744
0.25	1.1	3.5	585
Pan	---	1.1	184
Total			16774

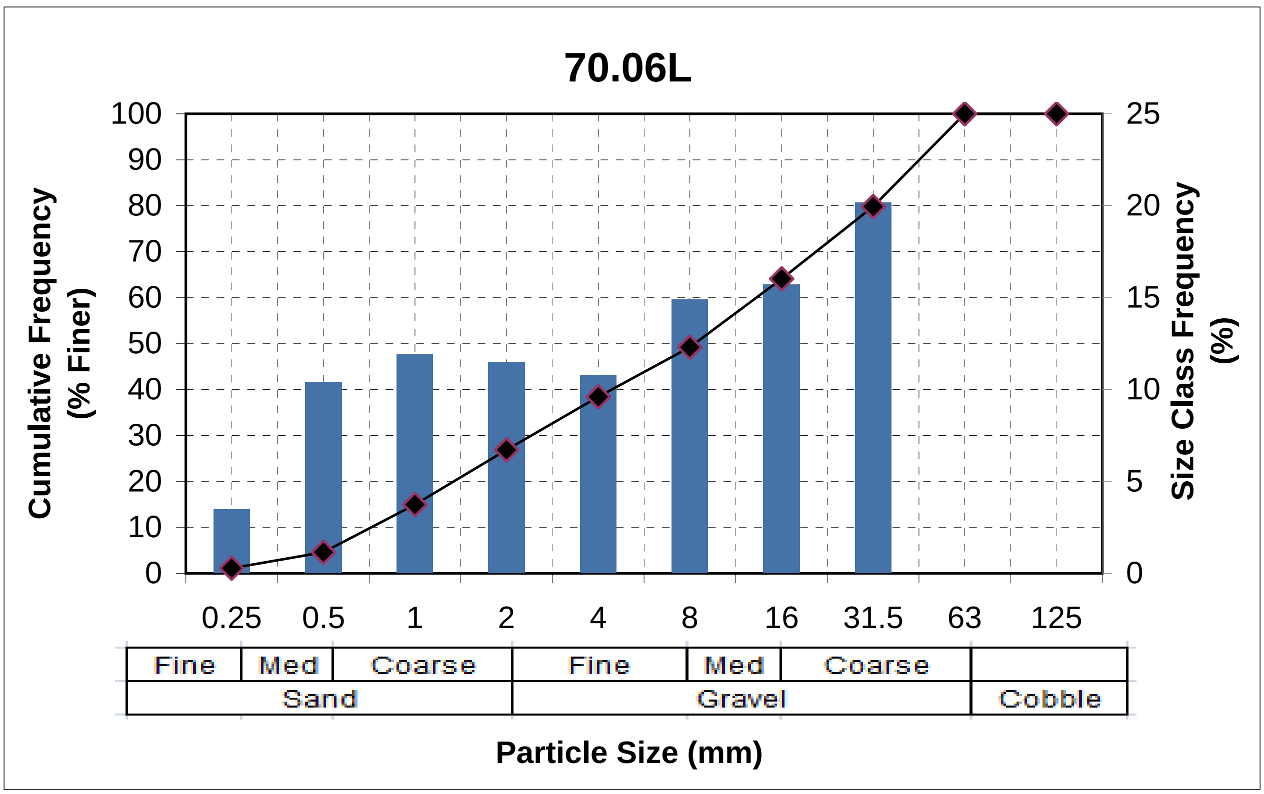


Figure C-19. Patch 70.13R Gravel Size and Percentage (n=4).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	91.1	8.9	1565
16	63.4	27.7	4876
8	41.5	21.9	3853
4	29.8	11.8	2070
2	20.4	9.4	1662
1	11.7	8.7	1529
0.5	4.3	7.4	1302
0.25	1.2	3.1	548
Pan	---	1.2	206
Total			17611

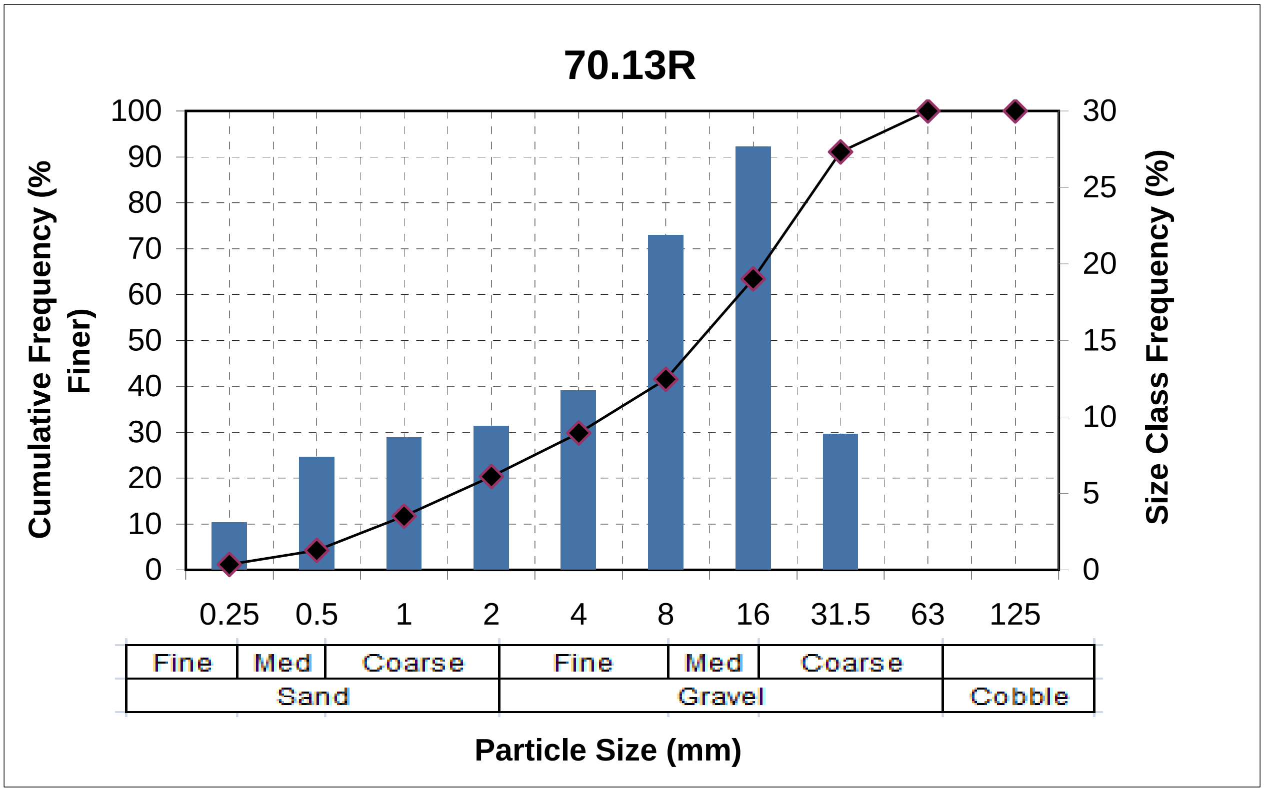


Figure C-20. Patch 70.14L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	98.2	1.8	63
16	76.1	22.1	786
8	56.1	20.0	712
4	46.3	9.9	351
2	36.6	9.6	342
1	24.7	11.9	425
0.5	8.2	16.5	586
0.25	1.2	7.0	249
Pan	---	1.2	44
Total			3558

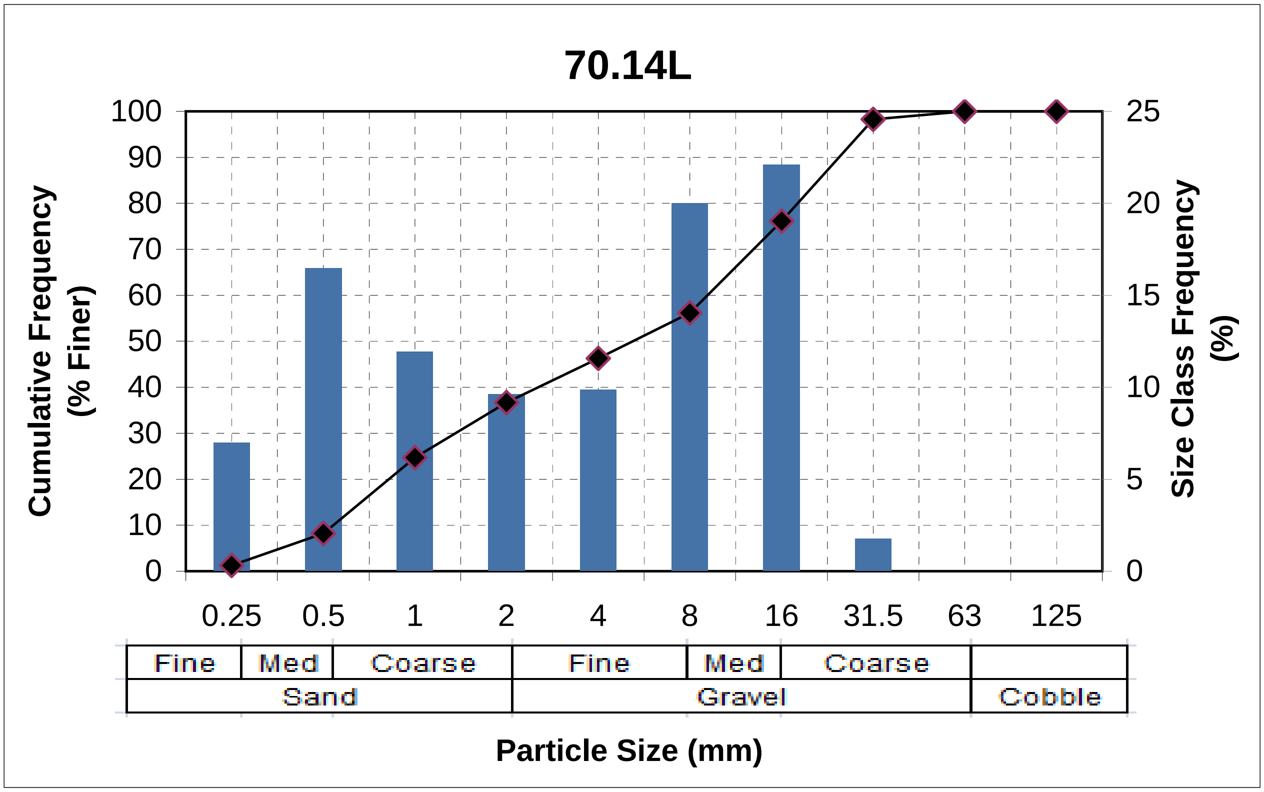


Figure C-21. Patch 70.17L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	98.4	1.6	64
16	76.6	21.8	853
8	50.5	26.0	1018
4	40.2	10.4	405
2	31.6	8.6	335
1	21.2	10.4	405
0.5	8.3	12.9	505
0.25	1.8	6.5	256
Pan	---	1.8	70
Total			3911

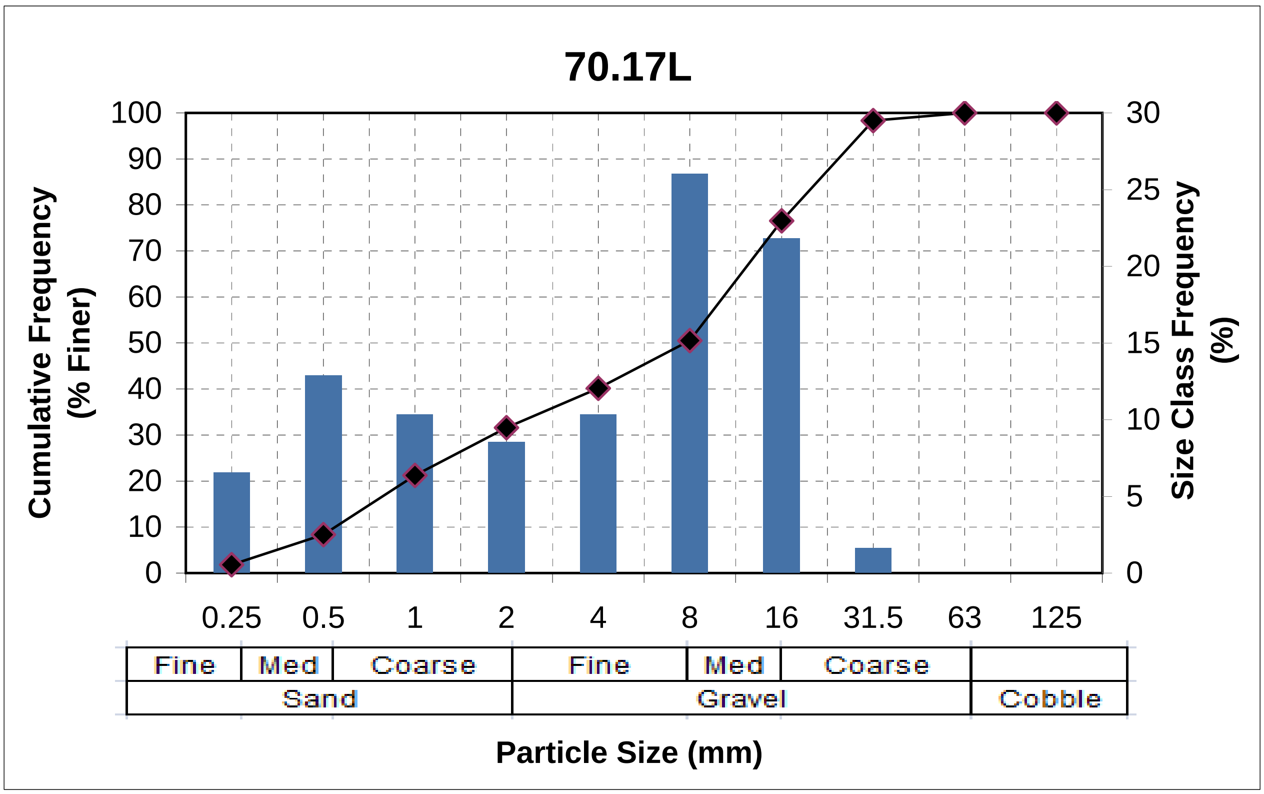


Figure C-22. Patch 70.18R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	69.8	30.2	970
16	51.5	18.3	590
8	37.7	13.8	445
4	27.1	10.6	340
2	17.4	9.6	310
1	10.6	6.8	219
0.5	7.3	3.4	108
0.25	3.7	3.6	115
Pan	---	3.7	119
Total			3216

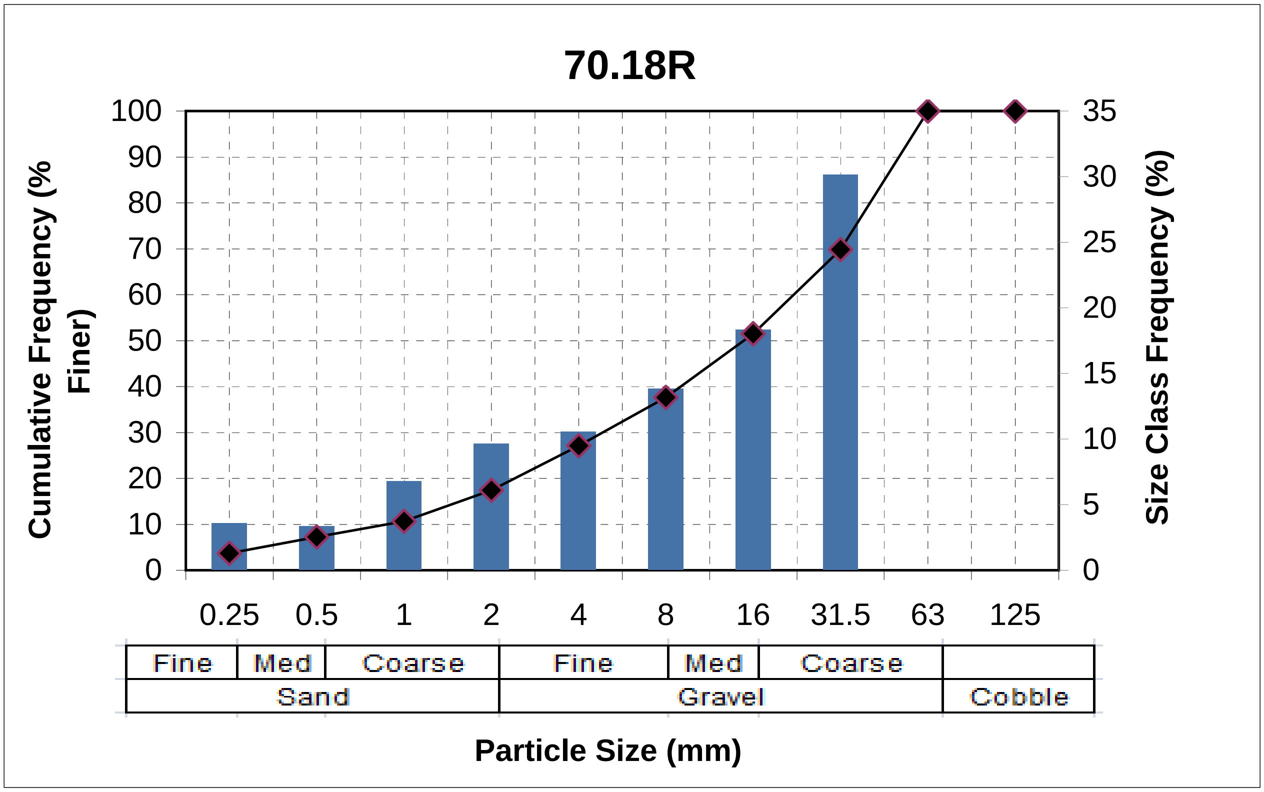


Figure C-23. Patch 70.20L Gravel Size and Percentage (n=3).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	87.3	12.7	2200
31.5	64.1	23.2	4030
16	45.6	18.5	3215
8	34.3	11.3	1955
4	26.8	7.5	1300
2	19.5	7.3	1265
1	11.9	7.7	1335
0.5	3.2	8.7	1510
0.25	0.8	2.4	417
Pan	---	0.8	131
Total			17358

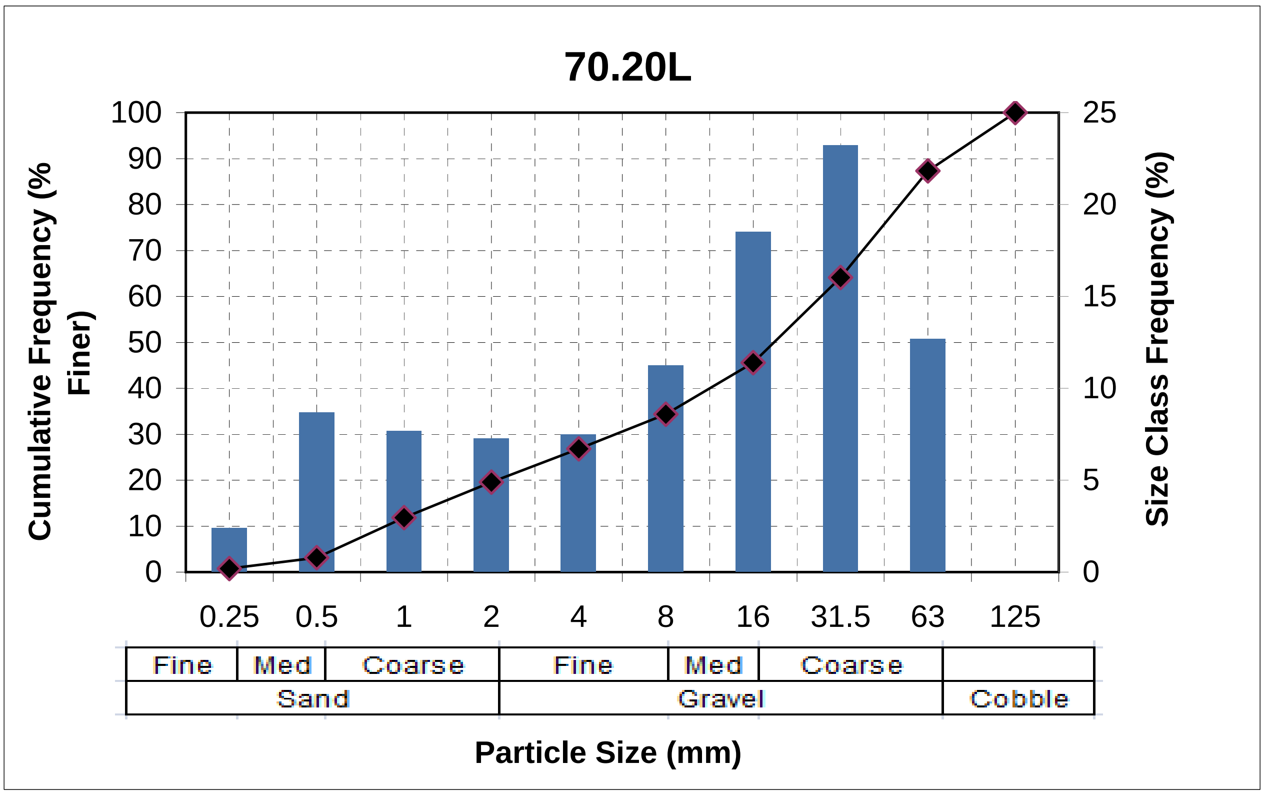


Figure C-24. Patch 70.25L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	61.2	38.8	2360
16	39.1	22.1	1345
8	32.4	6.7	405
4	27.1	5.3	325
2	21.3	5.8	350
1	10.8	10.5	638
0.5	1.9	8.9	540
0.25	0.3	1.6	100
Pan	---	0.3	18
Total			6081

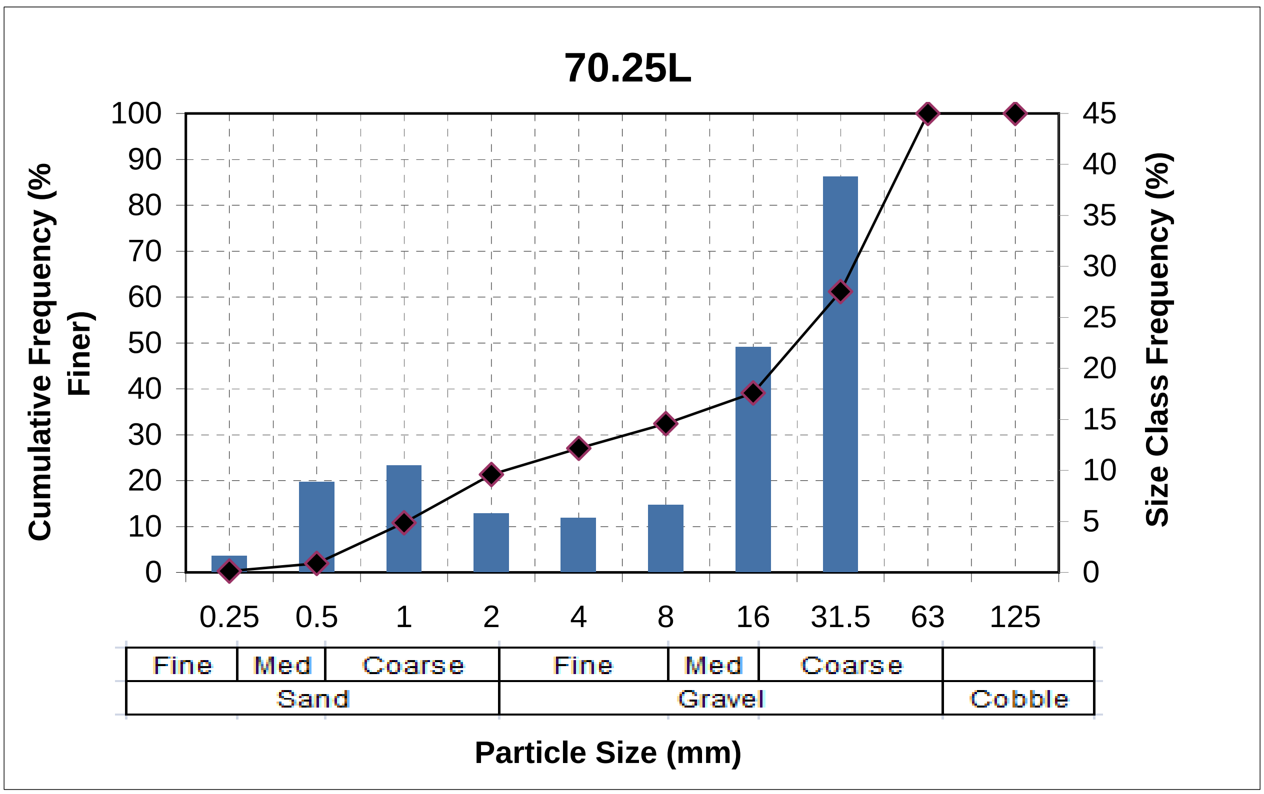


Figure C-25. Patch 70.26R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	79.3	20.7	797
31.5	63.6	15.7	605
16	46.9	16.6	641
8	34.0	12.9	498
4	26.3	7.7	297
2	18.0	8.3	321
1	6.9	11.1	428
0.5	2.6	4.3	164
0.25	1.6	1.0	38
Pan	---	1.6	62
Total			3851

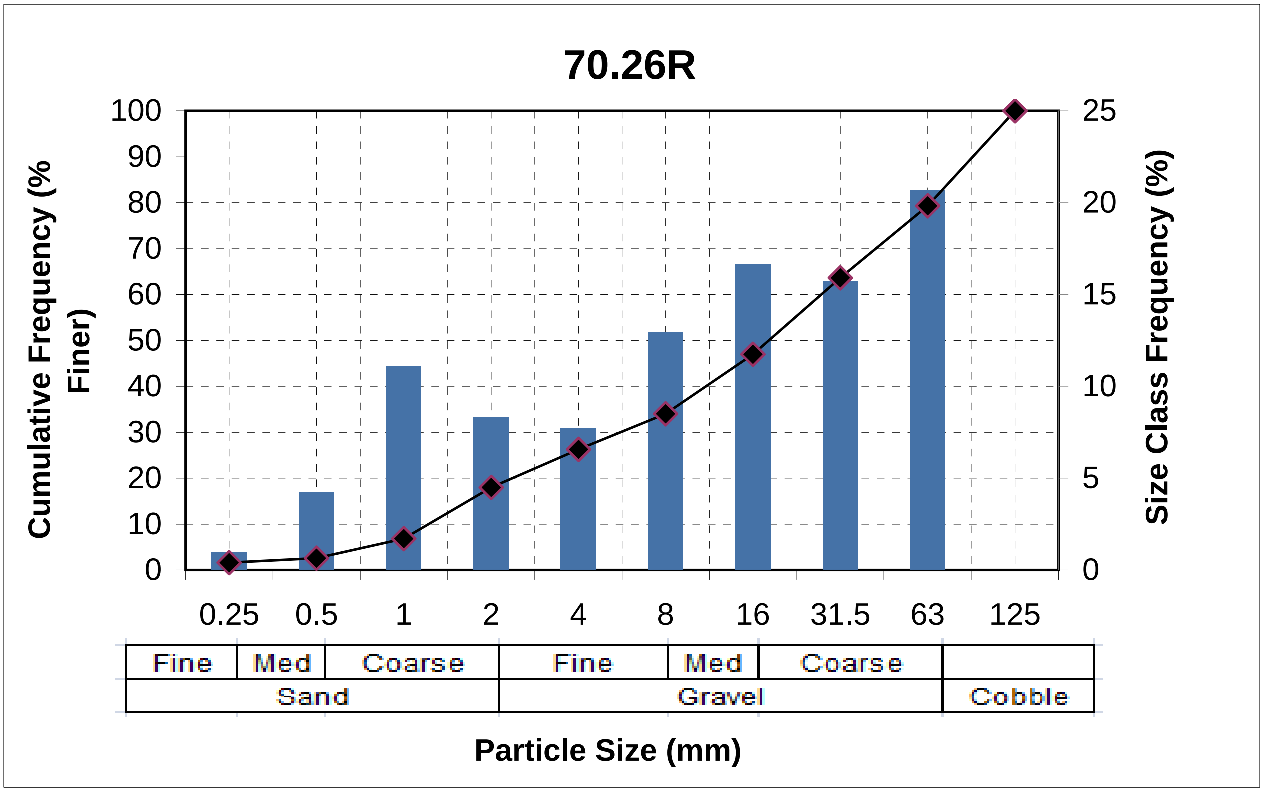


Figure C-26. Patch 70.27L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	79.3	20.7	1250
31.5	51.3	28.0	1690
16	37.0	14.3	860
8	25.7	11.4	685
4	19.6	6.0	365
2	16.2	3.4	205
1	12.4	3.8	232
0.5	3.3	9.0	545
0.25	0.4	3.0	179
Pan	---	0.4	23
Total			6034

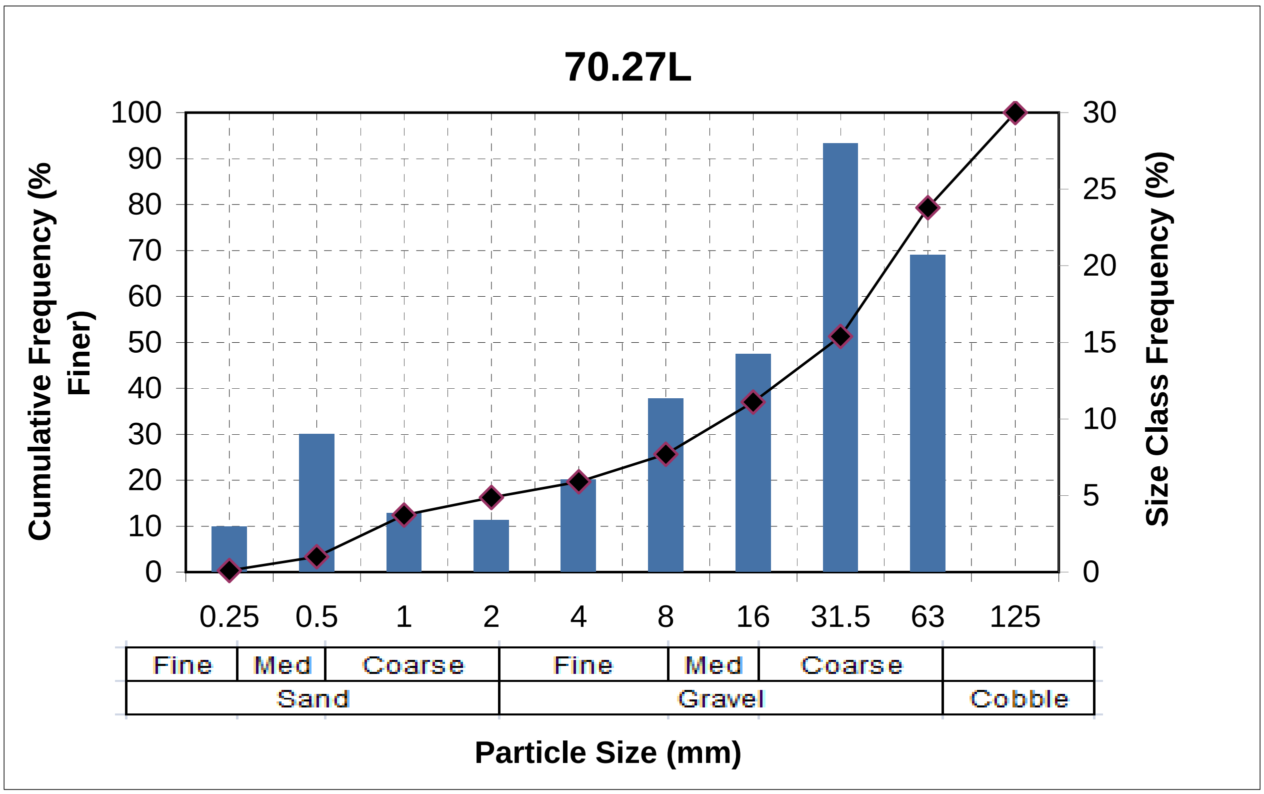


Figure C-27. Patch 70.28R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	86.0	14.0	681
16	46.1	39.8	1935
8	29.5	16.7	810
4	23.0	6.5	316
2	18.7	4.3	209
1	15.1	3.5	172
0.5	12.6	2.5	122
0.25	6.2	6.4	311
Pan	---	6.2	301
Total			4857

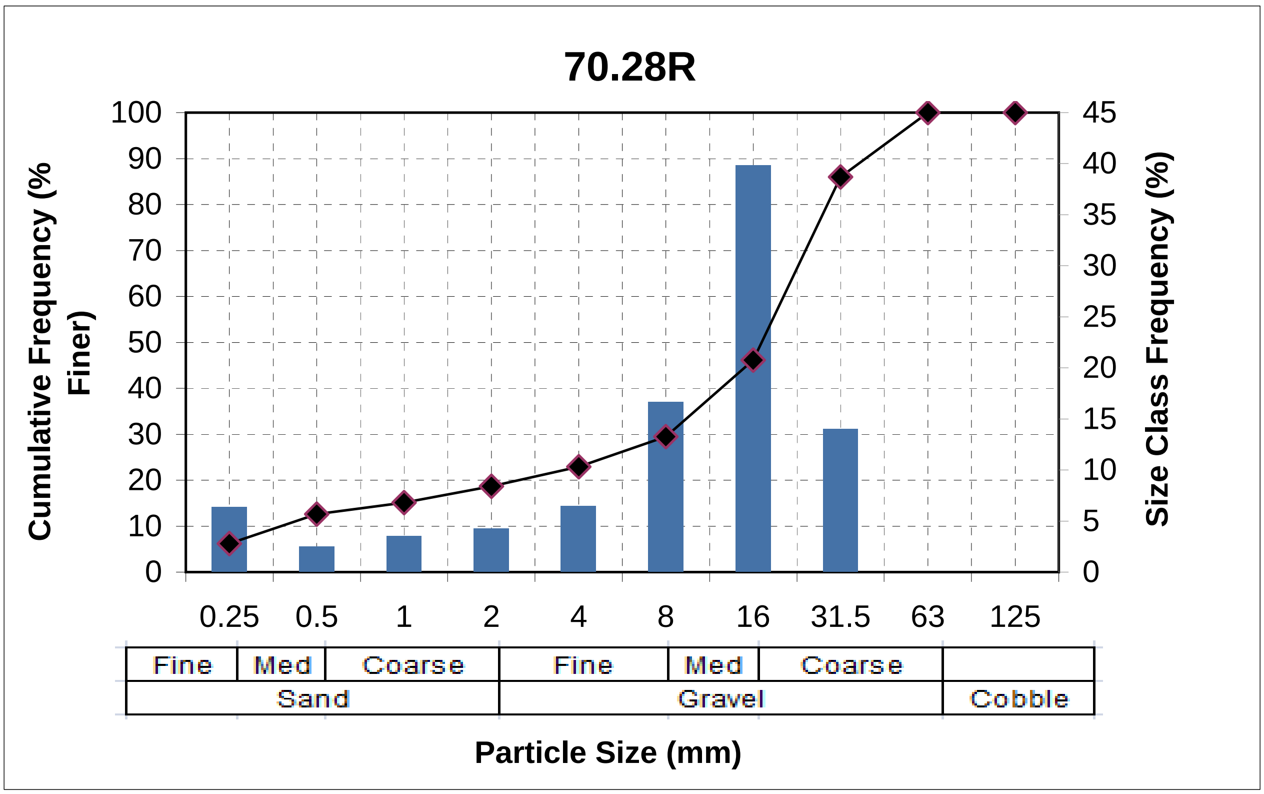


Figure C-28. Patch 70.35L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	80.2	19.8	1075
16	57.2	23.0	1250
8	42.3	14.9	810
4	32.2	10.1	550
2	20.7	11.5	625
1	12.4	8.4	454
0.5	3.8	8.6	465
0.25	0.8	3.0	164
Pan	---	0.8	43
Total			5436

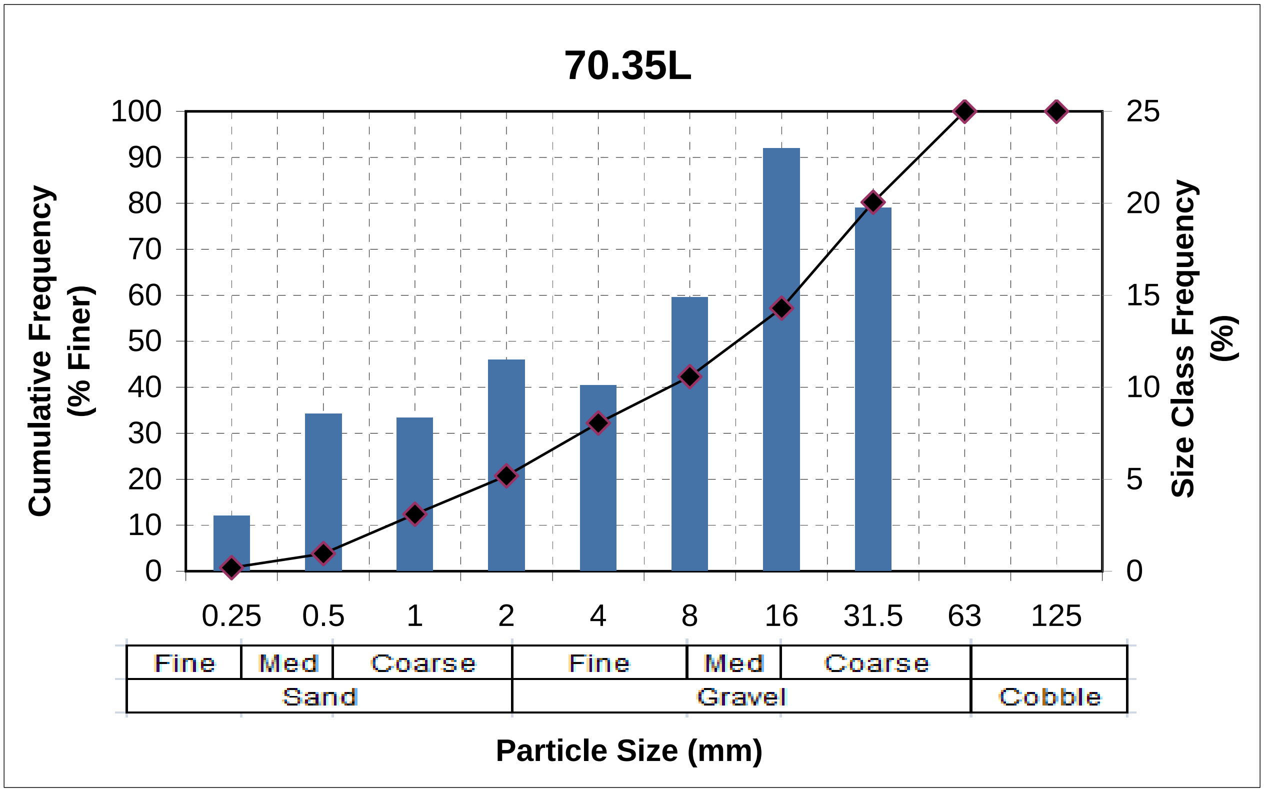


Figure C-29. Patch 70.39L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	92.3	7.7	365
16	66.3	26.0	1230
8	54.4	11.8	560
4	46.0	8.4	395
2	29.0	17.0	805
1	16.5	12.5	592
0.5	3.2	13.3	630
0.25	0.5	2.6	124
Pan	---	0.5	25
Total			4726

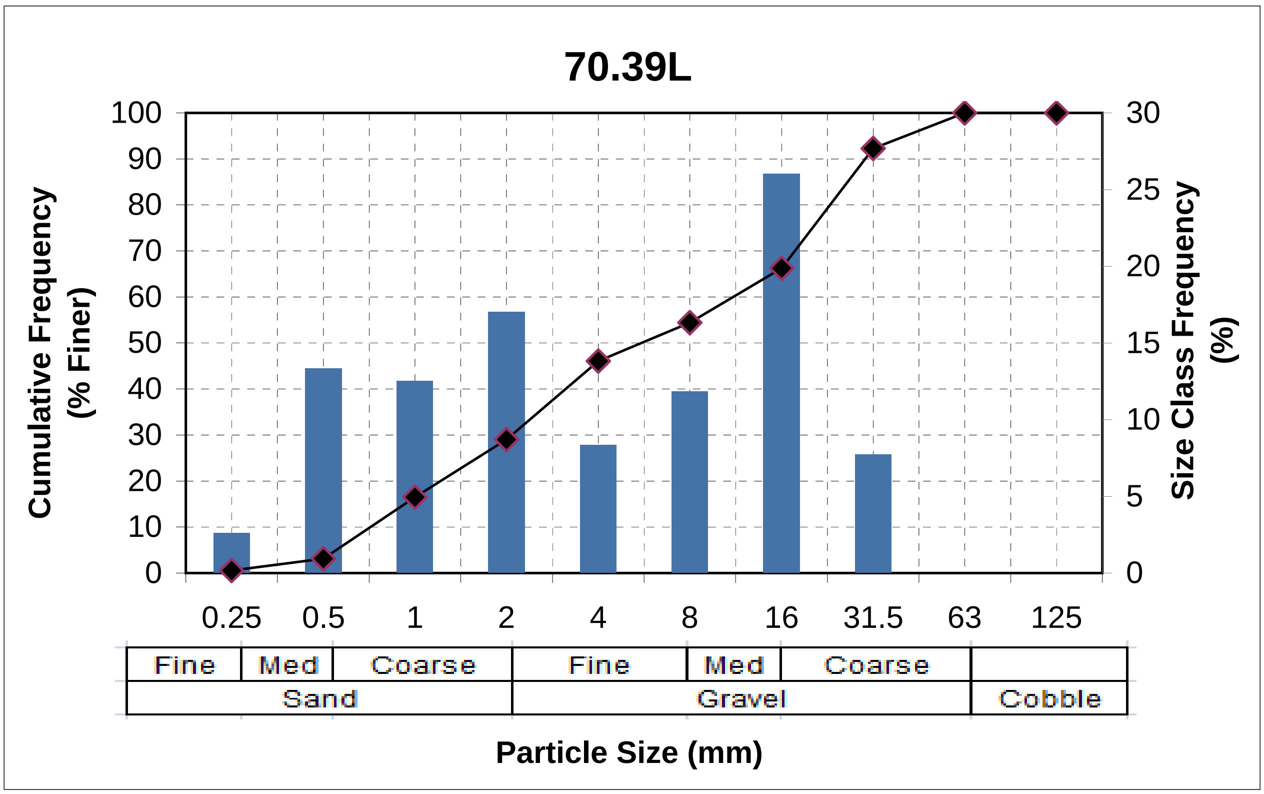


Figure C-30. Patch 70.65R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	91.3	8.7	302
16	67.8	23.5	815
8	53.6	14.2	493
4	40.6	13.0	452
2	26.6	14.0	485
1	17.4	9.2	318
0.5	7.6	9.8	340
0.25	1.2	6.4	221
Pan	---	1.2	43
Total			3469

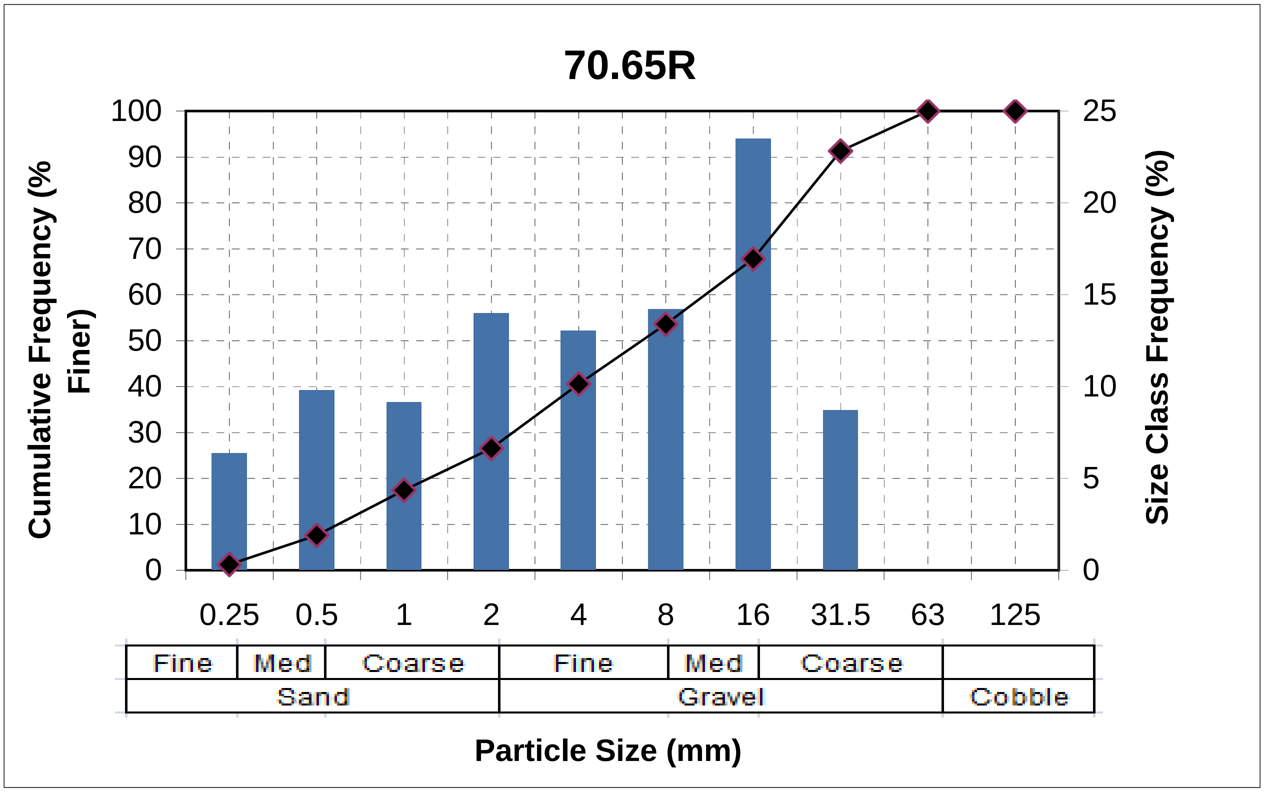


Figure C-31. Patch 70.77R Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	93.1	6.9	549
31.5	79.7	13.4	1077
16	59.1	20.6	1646
8	44.4	14.7	1179
4	33.5	10.9	873
2	21.8	11.8	942
1	10.7	11.0	883
0.5	2.8	8.0	639
0.25	0.5	2.2	177
Pan	---	0.5	44
Total			8009

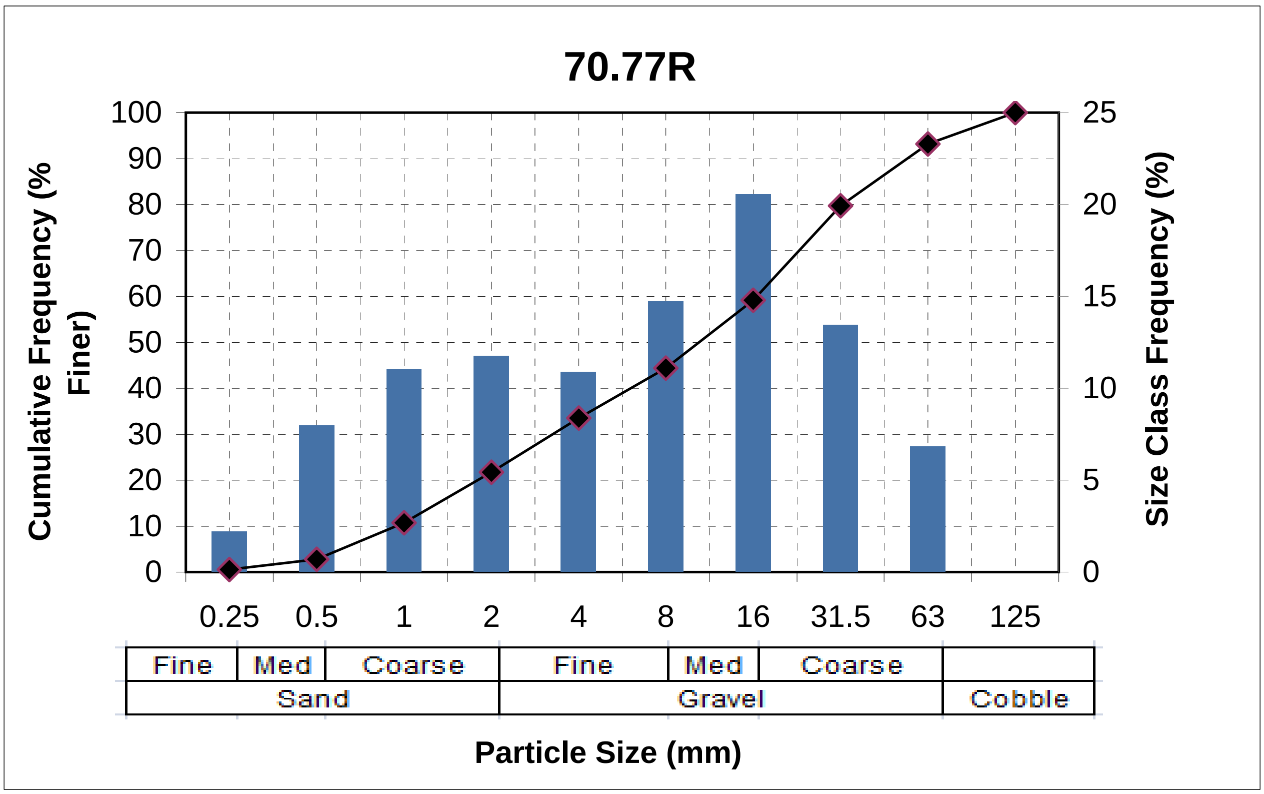


Figure C-32. Patch 70.83R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	90.7	9.3	386
16	64.4	26.3	1089
8	56.4	7.9	328
4	50.2	6.3	259
2	40.6	9.5	395
1	24.6	16.0	663
0.5	10.6	14.0	578
0.25	3.3	7.3	302
Pan	---	3.3	138
Total			4138

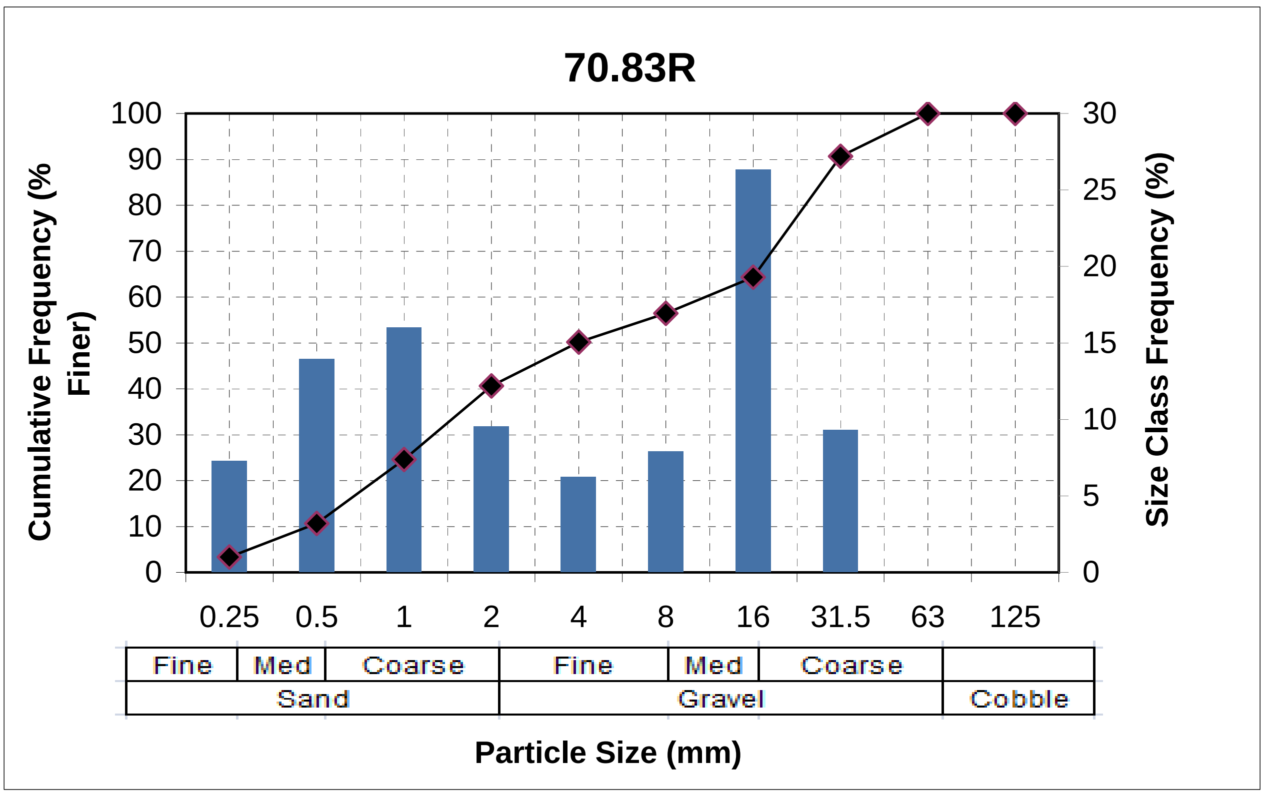


Figure C-33. Patch 70.88R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	98.5	1.5	49
16	74.2	24.3	804
8	52.5	21.7	718
4	37.7	14.8	489
2	25.9	11.8	390
1	15.3	10.5	348
0.5	6.1	9.2	305
0.25	2.4	3.7	122
Pan	---	2.4	80
Total			3305

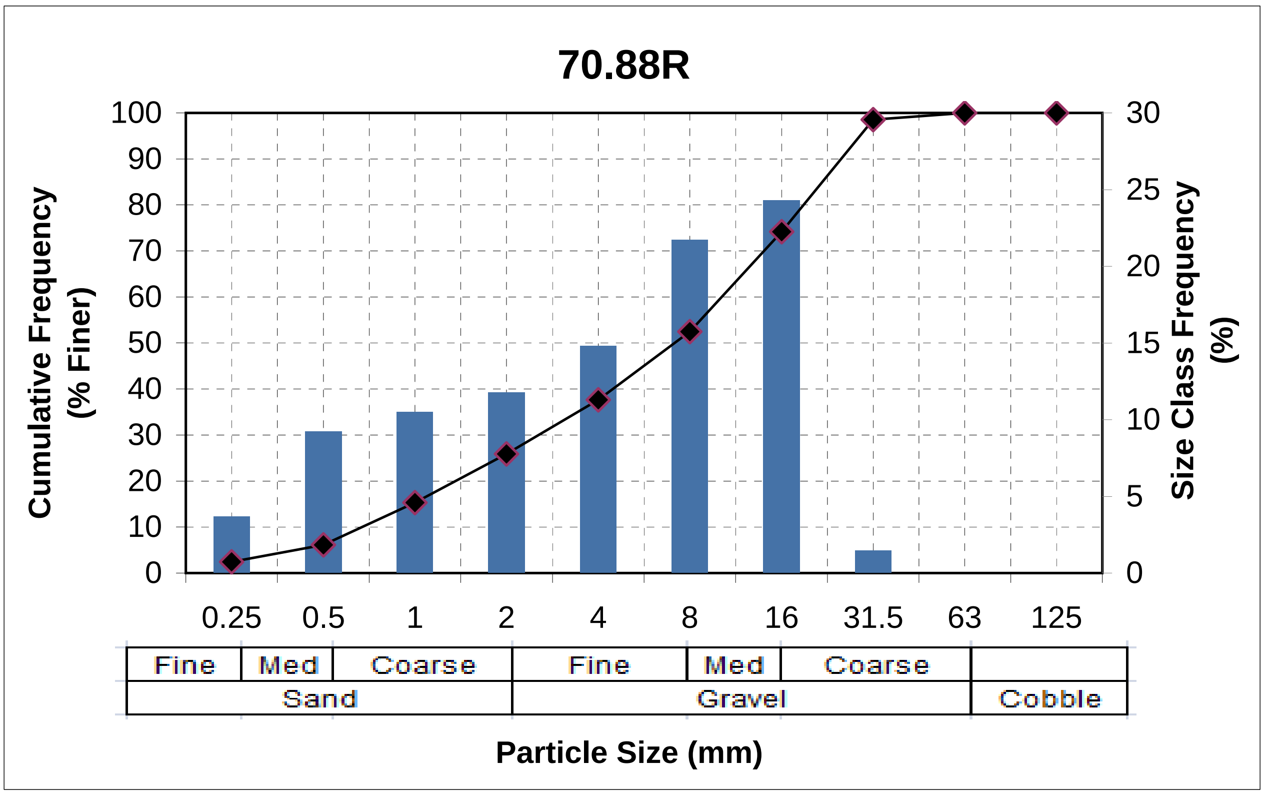


Figure C-34. Patch 71.23L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	85.5	14.5	531
16	50.0	35.6	1305
8	33.3	16.6	610
4	22.0	11.3	415
2	12.3	9.8	358
1	4.8	7.4	273
0.5	2.3	2.5	91
0.25	0.8	1.6	58
Pan	---	0.8	28
Total			3669

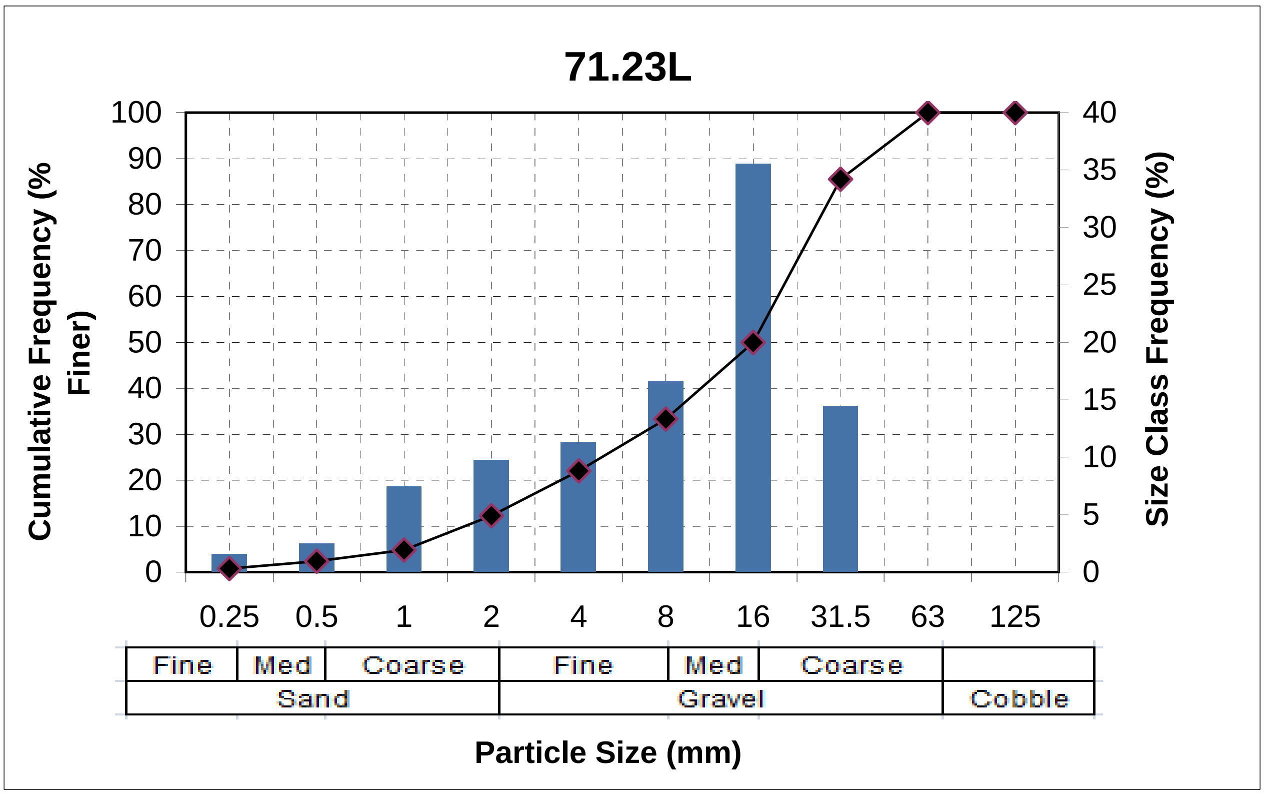


Figure C-35. Patch 71.26L Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	97.7	2.3	175
16	79.0	18.7	1430
8	62.5	16.5	1265
4	47.0	15.5	1188
2	29.7	17.3	1321
1	14.3	15.5	1185
0.5	8.0	6.3	483
0.25	2.4	5.5	423
Pan	---	2.4	186
Total			7656

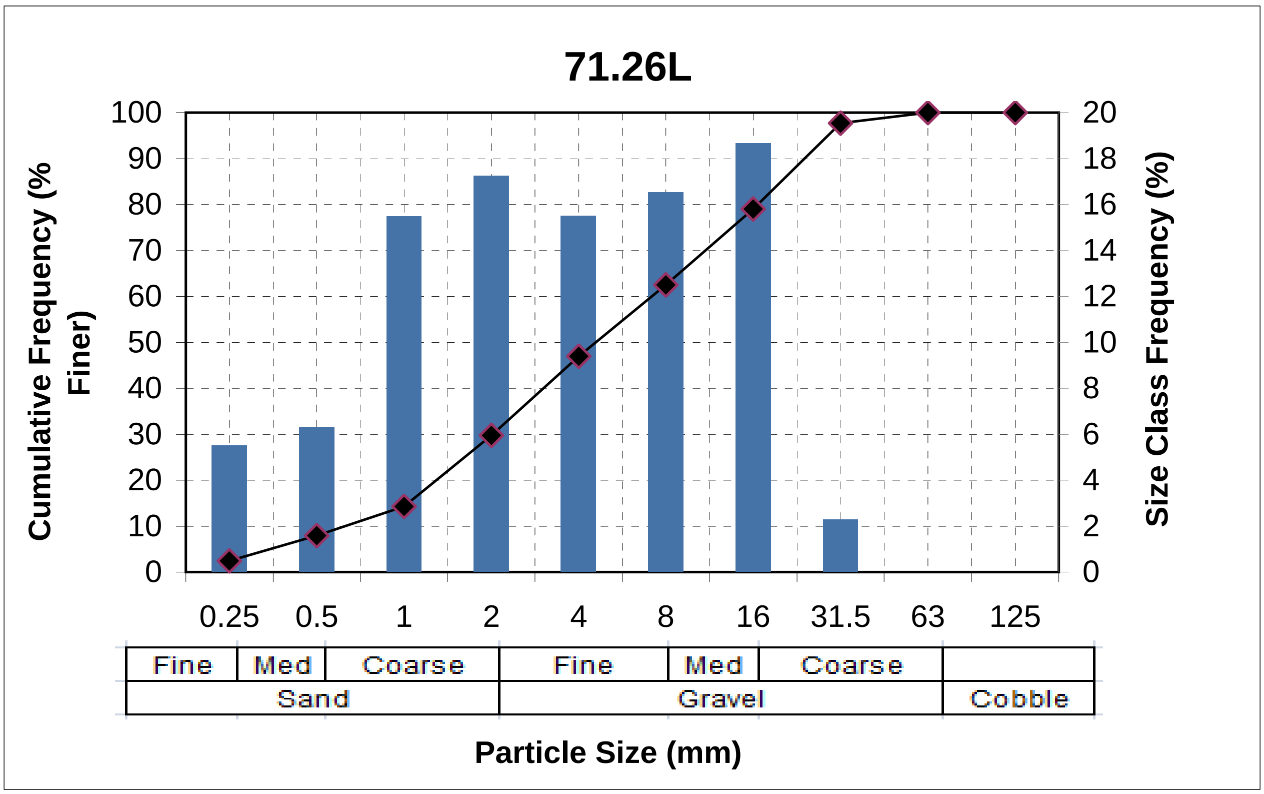


Figure C-36. Patch 71.30L Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	90.2	9.8	784
16	66.3	23.8	1898
8	48.0	18.3	1461
4	34.7	13.3	1061
2	21.1	13.6	1085
1	9.1	12.0	956
0.5	5.1	4.0	316
0.25	2.0	3.1	246
Pan	---	2.0	160
Total			7967

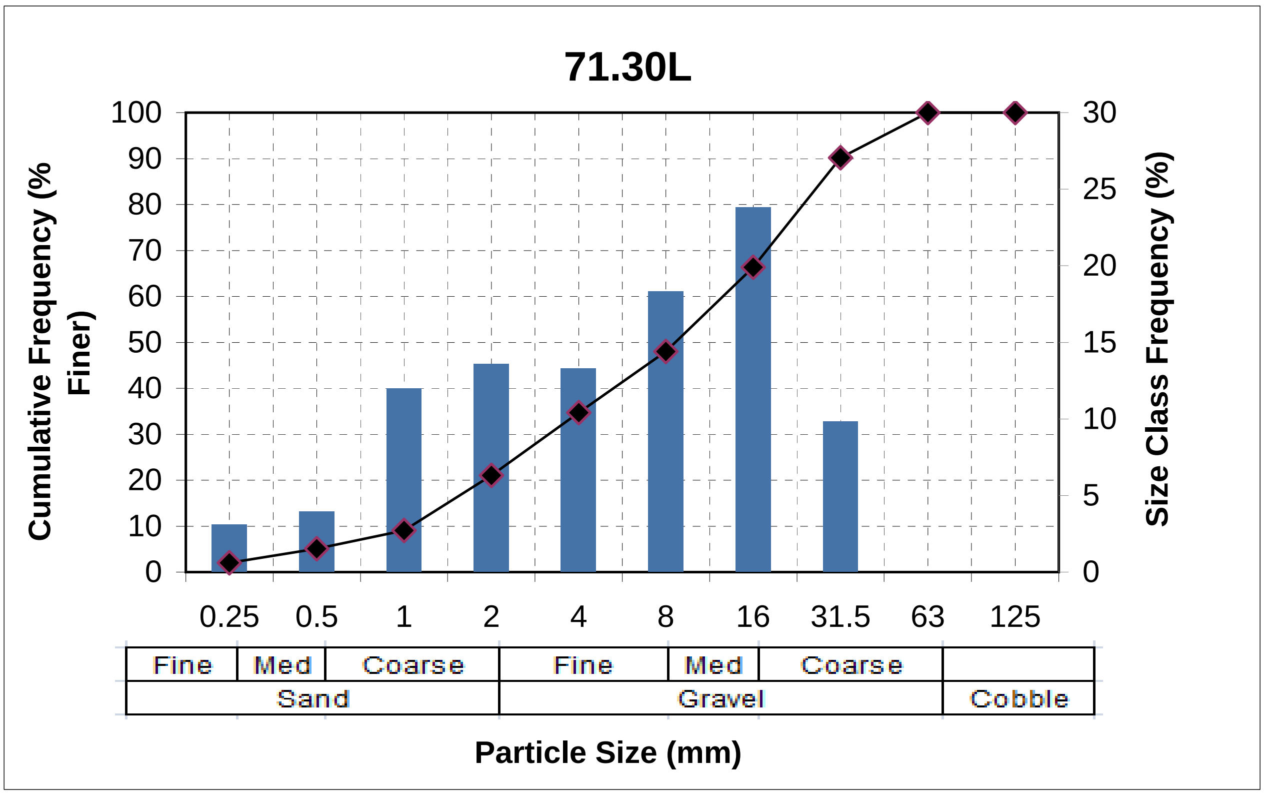


Figure C-37. Patch 71.52R Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	92.2	7.8	676
16	73.4	18.8	1615
8	55.3	18.1	1555
4	44.1	11.3	969
2	30.7	13.4	1155
1	19.3	11.4	983
0.5	8.0	11.2	966
0.25	1.6	6.4	555
Pan	---	1.6	138
Total			8612

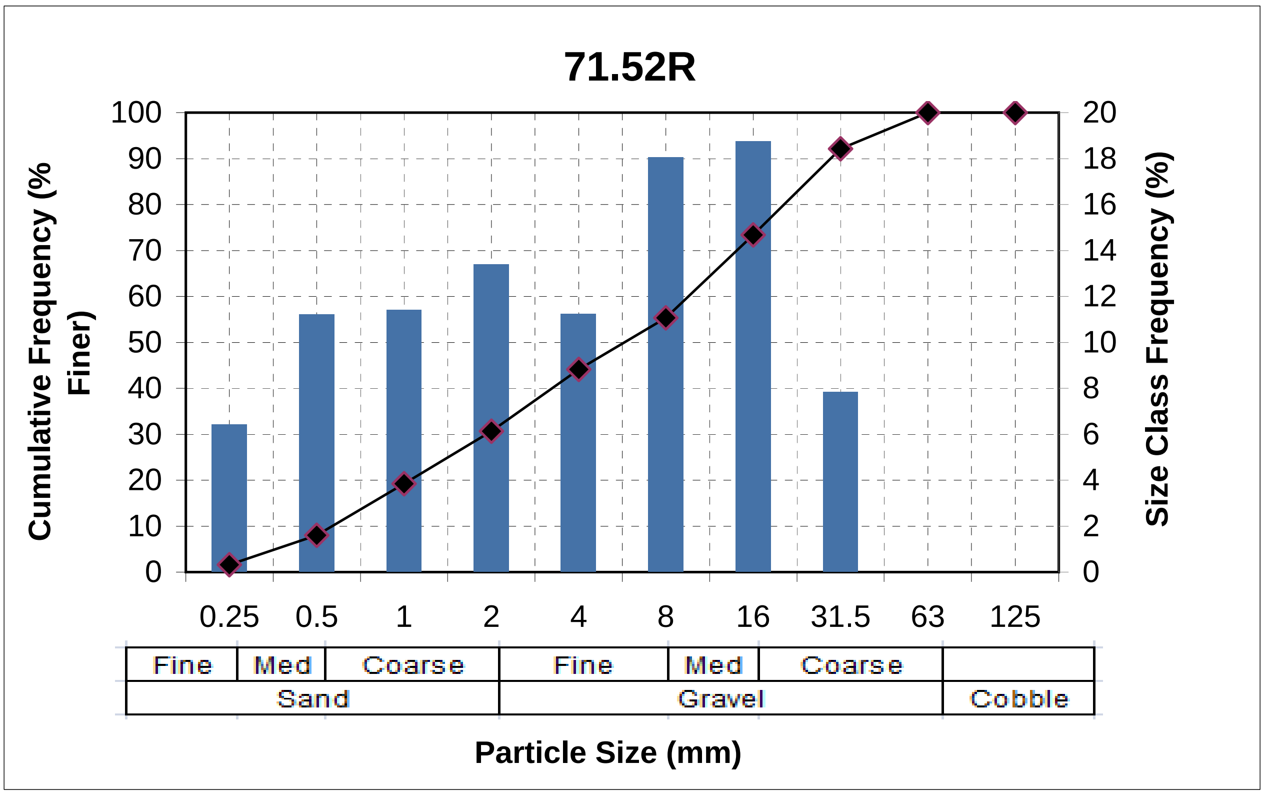


Figure C-38. Patch 71.66L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	90.5	9.5	423
31.5	57.6	32.9	1461
16	39.4	18.2	810
8	31.3	8.1	362
4	25.7	5.5	246
2	19.9	5.8	259
1	9.4	10.5	468
0.5	2.2	7.2	321
0.25	0.5	1.6	73
Pan	---	0.5	23
Total			4446

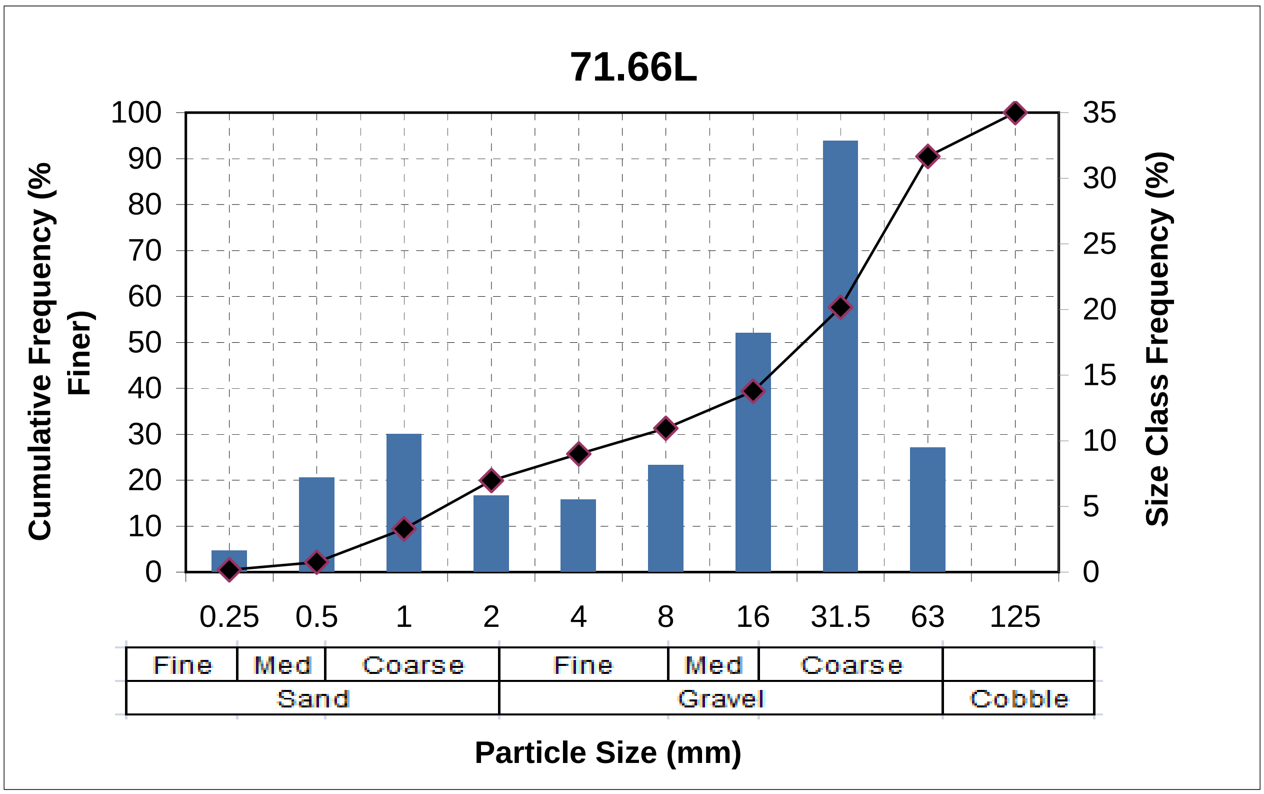


Figure C-39. Patch 71.69L Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	80.2	19.8	2034
31.5	71.3	8.9	915
16	44.0	27.3	2813
8	27.8	16.2	1663
4	20.9	7.0	719
2	14.3	6.6	676
1	6.3	8.0	827
0.5	2.0	4.3	438
0.25	0.7	1.3	136
Pan	---	0.7	70
Total			10291

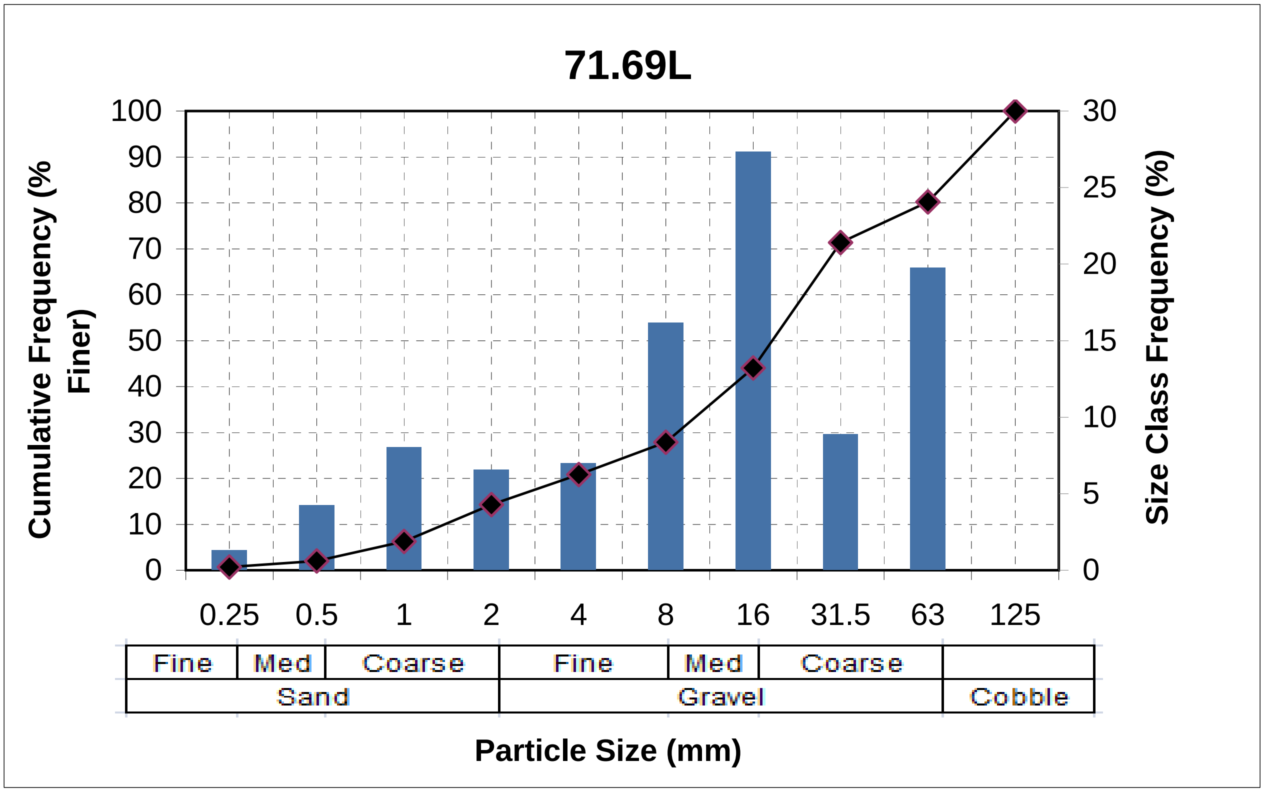


Figure C-40. Patch 71.71L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	80.1	19.9	655
16	62.2	17.9	590
8	40.6	21.6	712
4	24.9	15.7	517
2	11.6	13.3	439
1	3.6	8.0	265
0.5	0.5	3.0	100
0.25	0.1	0.4	14
Pan	---	0.1	3
Total			3295

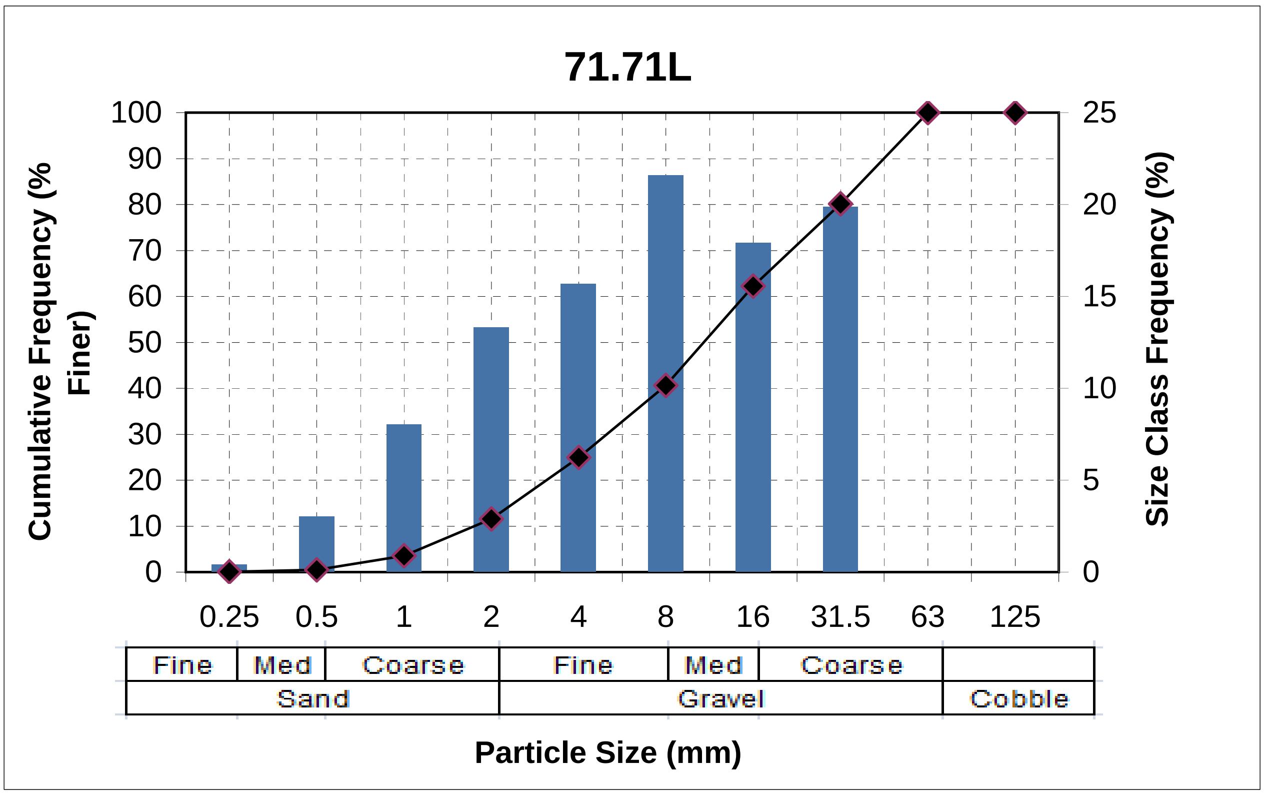


Figure C-41. Patch 71.74L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	76.1	23.9	853
16	53.9	22.3	796
8	27.4	26.5	948
4	17.5	9.8	352
2	7.5	10.0	358
1	3.2	4.4	156
0.5	0.8	2.4	86
0.25	0.2	0.5	19
Pan	---	0.2	8
Total			3576

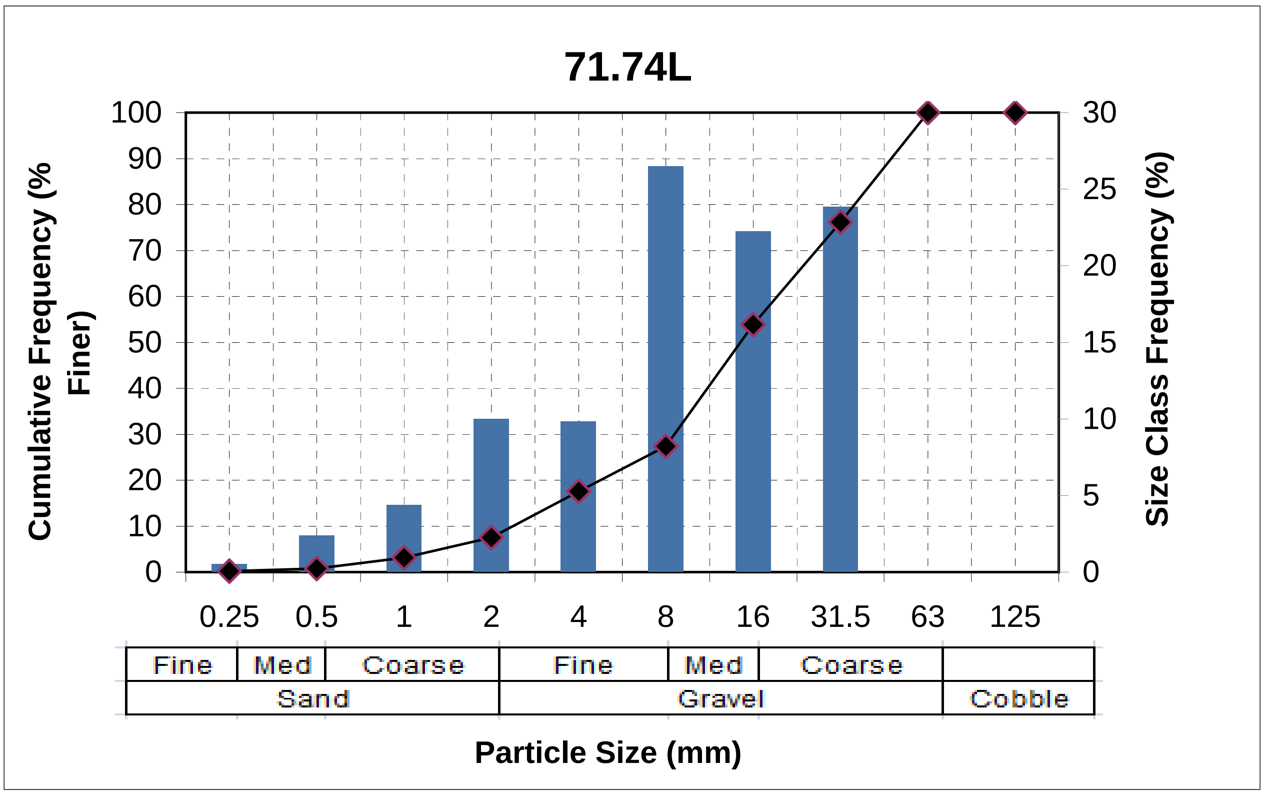


Figure C-42. Patch 71.91R Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	92.8	7.2	486
16	72.8	20.1	1362
8	27.6	45.2	3070
4	14.8	12.8	868
2	8.5	6.3	425
1	4.9	3.6	244
0.5	1.9	3.0	206
0.25	0.4	1.5	101
Pan	---	0.4	28
Total			6790

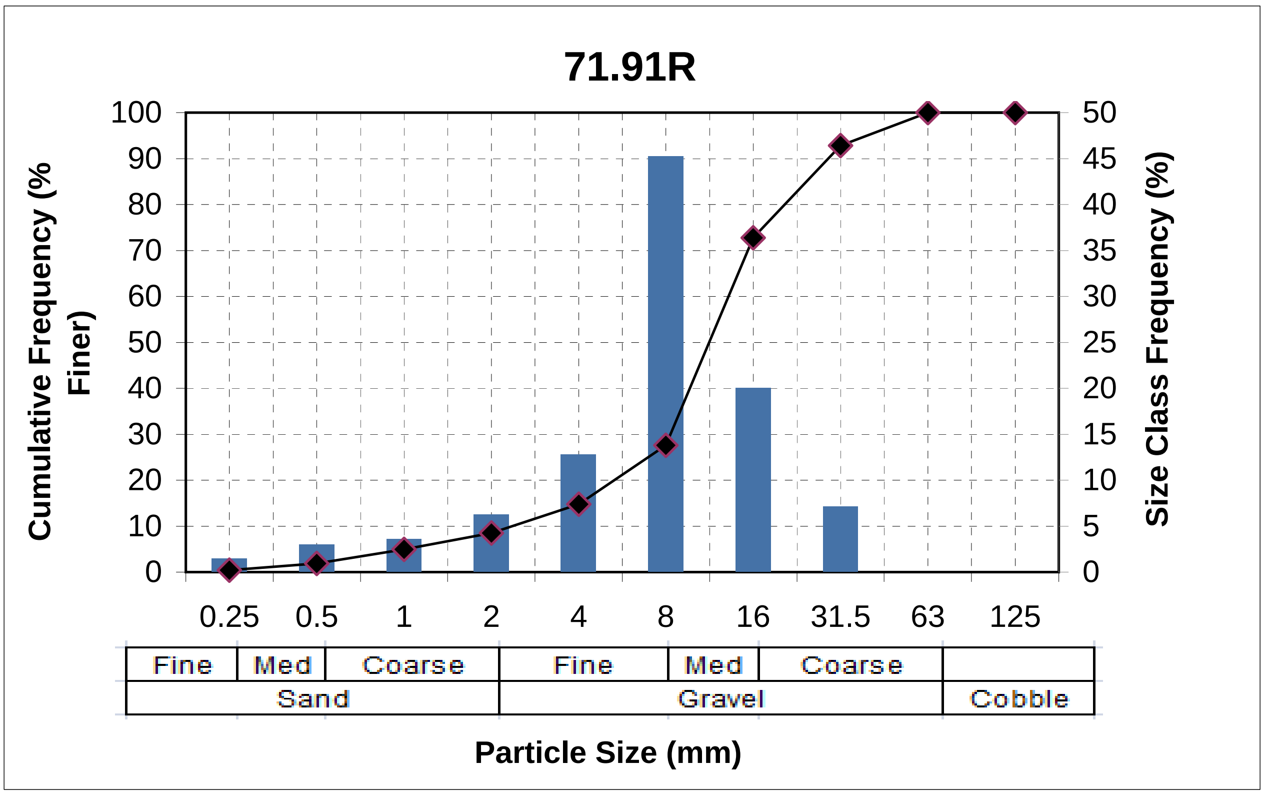


Figure C-43. Patch 72.24R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	96.6	3.4	122
16	62.8	33.8	1210
8	43.0	19.8	711
4	36.3	6.7	240
2	31.5	4.8	172
1	26.9	4.6	165
0.5	17.7	9.2	329
0.25	5.2	12.6	450
Pan	---	5.2	185
Total			3584

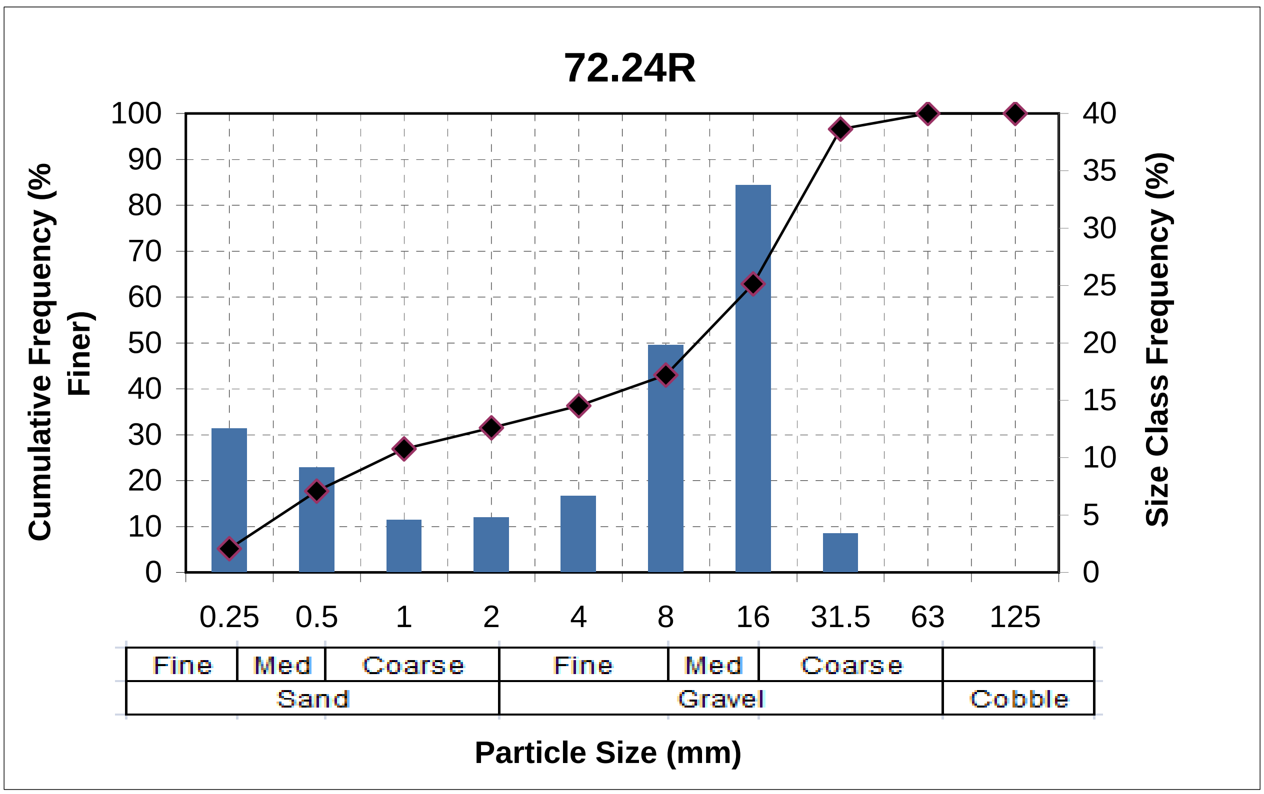


Figure C-44. Patch 72.42R Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	90.5	9.5	690
16	48.5	41.9	3031
8	16.5	32.0	2310
4	4.3	12.2	885
2	1.6	2.7	197
1	0.5	1.1	81
0.5	0.2	0.3	19
0.25	0.1	0.1	7
Pan	---	0.1	7
Total			7227

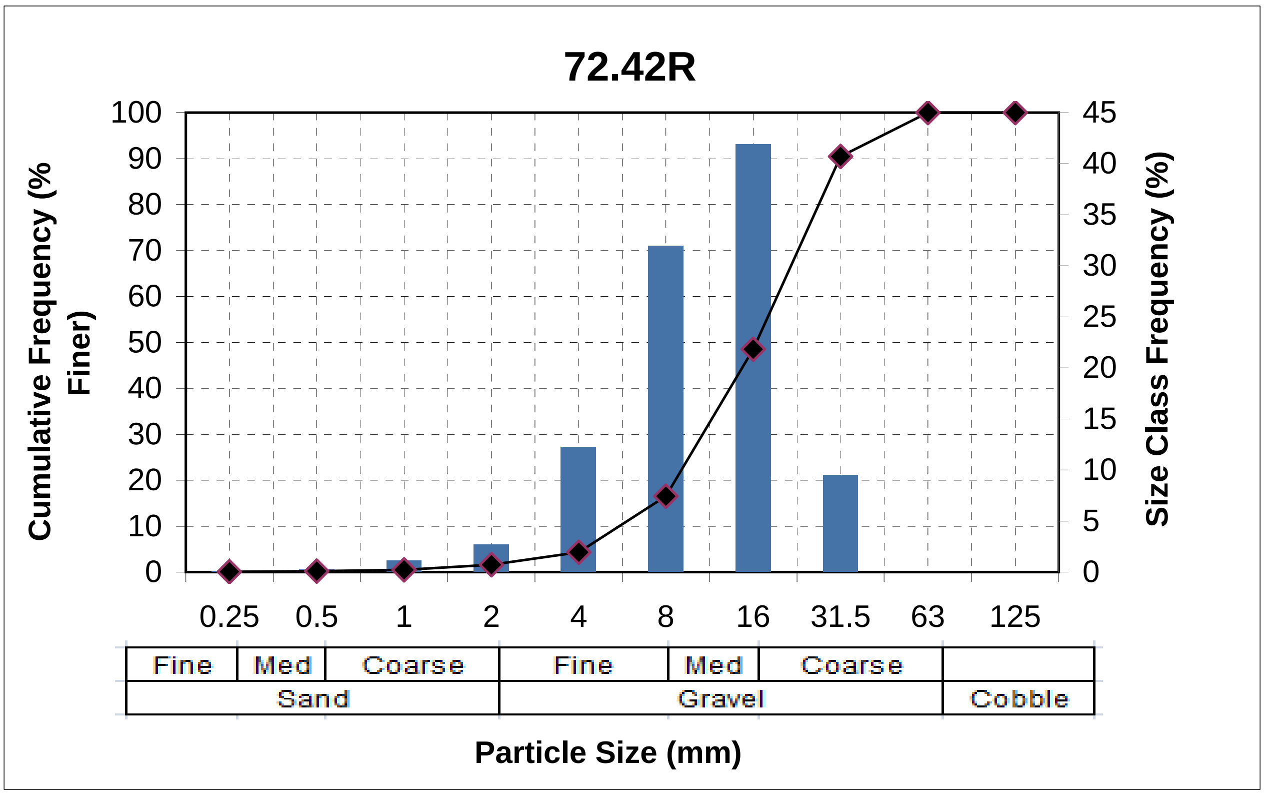


Figure C-45. Patch 72.47L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	95.7	4.3	158
16	79.1	16.6	618
8	59.7	19.4	720
4	39.4	20.3	755
2	17.0	22.4	831
1	1.9	15.1	560
0.5	0.2	1.7	64
0.25	0.1	0.1	4
Pan	---	0.1	2
Total			3712

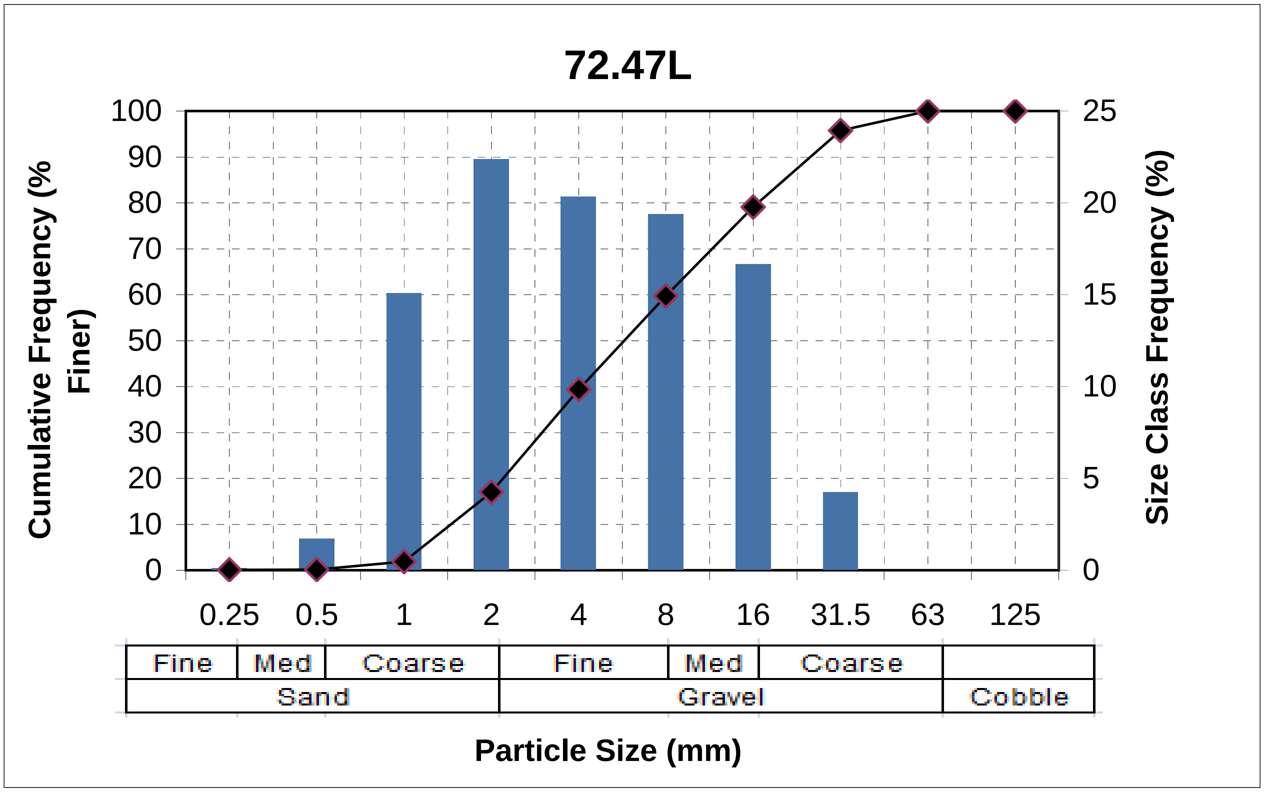


Figure C-46. Patch 72.53L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	91.9	8.1	302
16	77.7	14.2	530
8	52.9	24.9	930
4	35.5	17.3	648
2	25.9	9.6	360
1	16.0	9.9	370
0.5	5.3	10.8	402
0.25	0.9	4.3	162
Pan	---	0.9	35
Total			3739

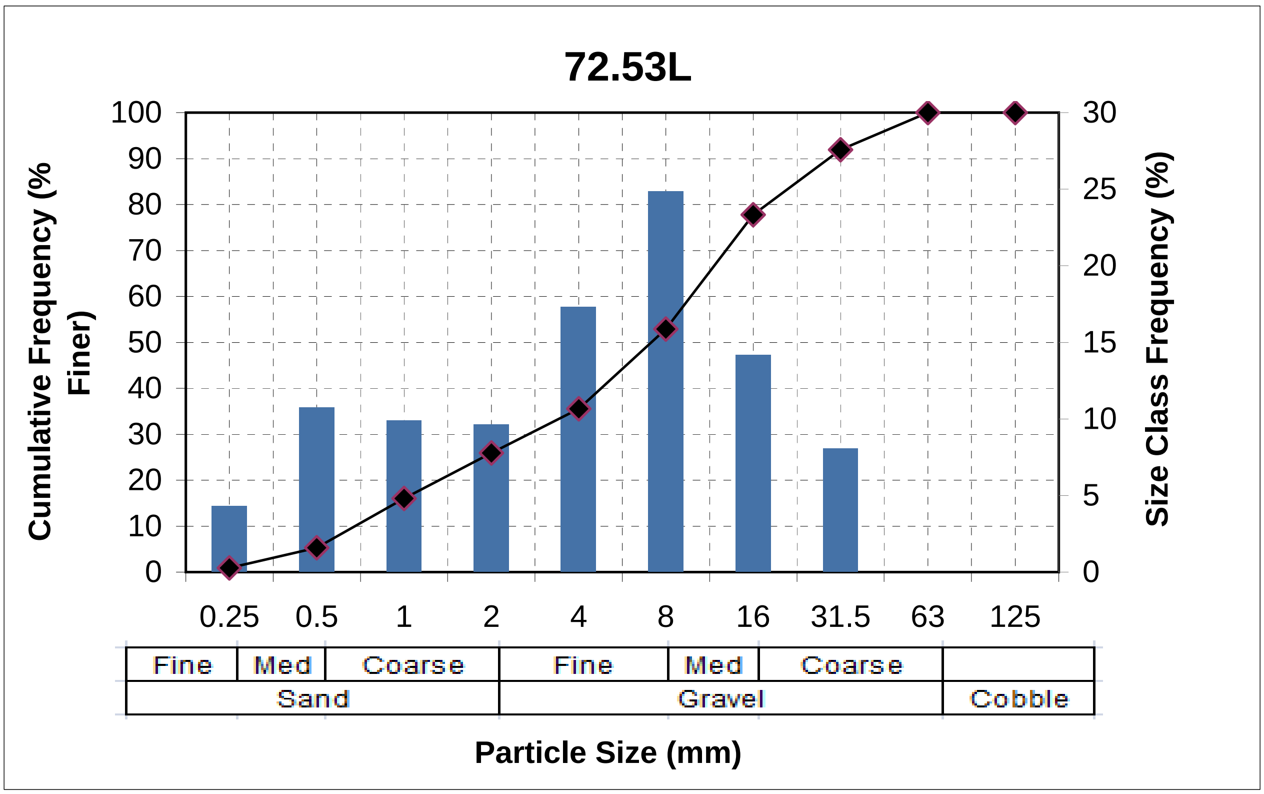


Figure C-47. Patch 72.56L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	90.7	9.3	468
16	74.7	16.0	803
8	64.0	10.7	540
4	56.3	7.6	384
2	48.6	7.8	390
1	39.4	9.1	459
0.5	20.9	18.5	930
0.25	6.1	14.9	748
Pan	---	6.1	305
Total			5027

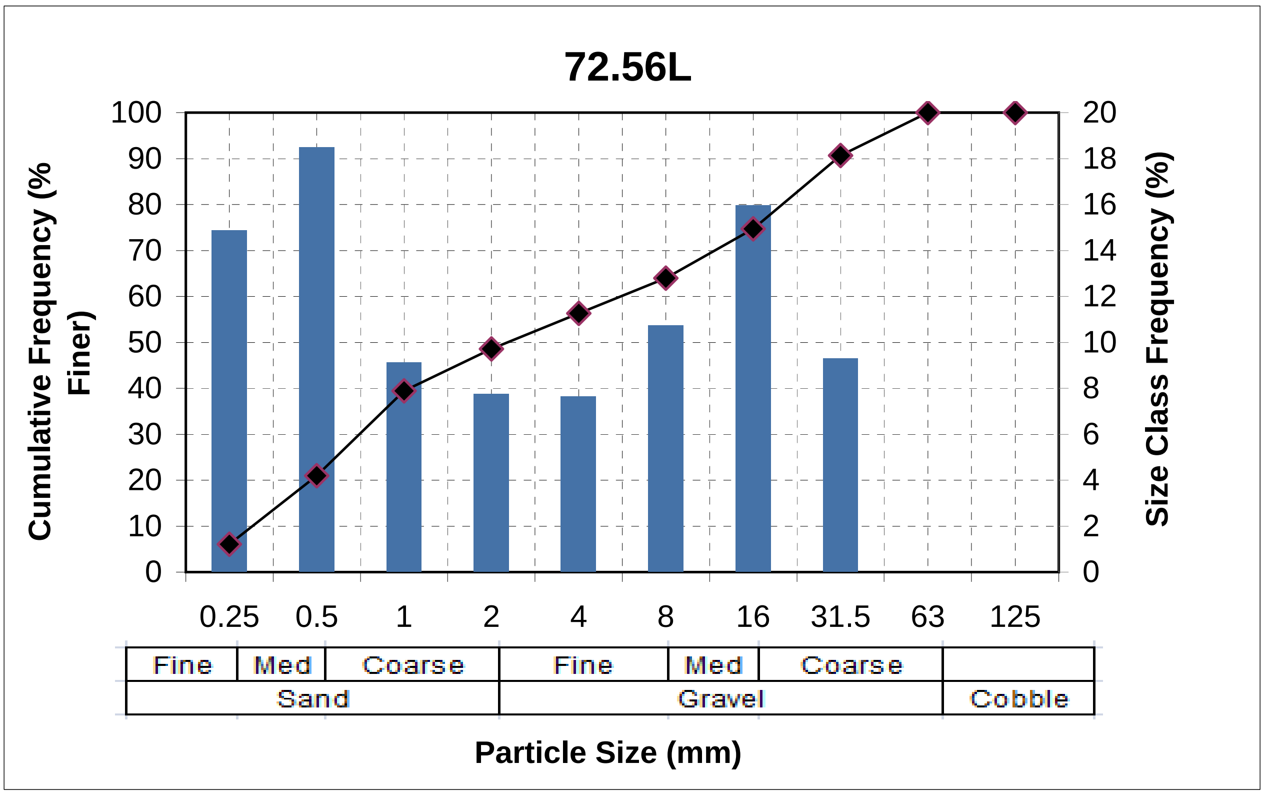


Figure C-48. Patch 72.67L Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	97.3	2.7	171
16	63.1	34.1	2127
8	39.6	23.6	1470
4	35.4	4.1	257
2	34.1	1.4	85
1	32.4	1.7	105
0.5	25.1	7.3	455
0.25	9.0	16.1	1004
Pan	---	9.0	560
Total			6234

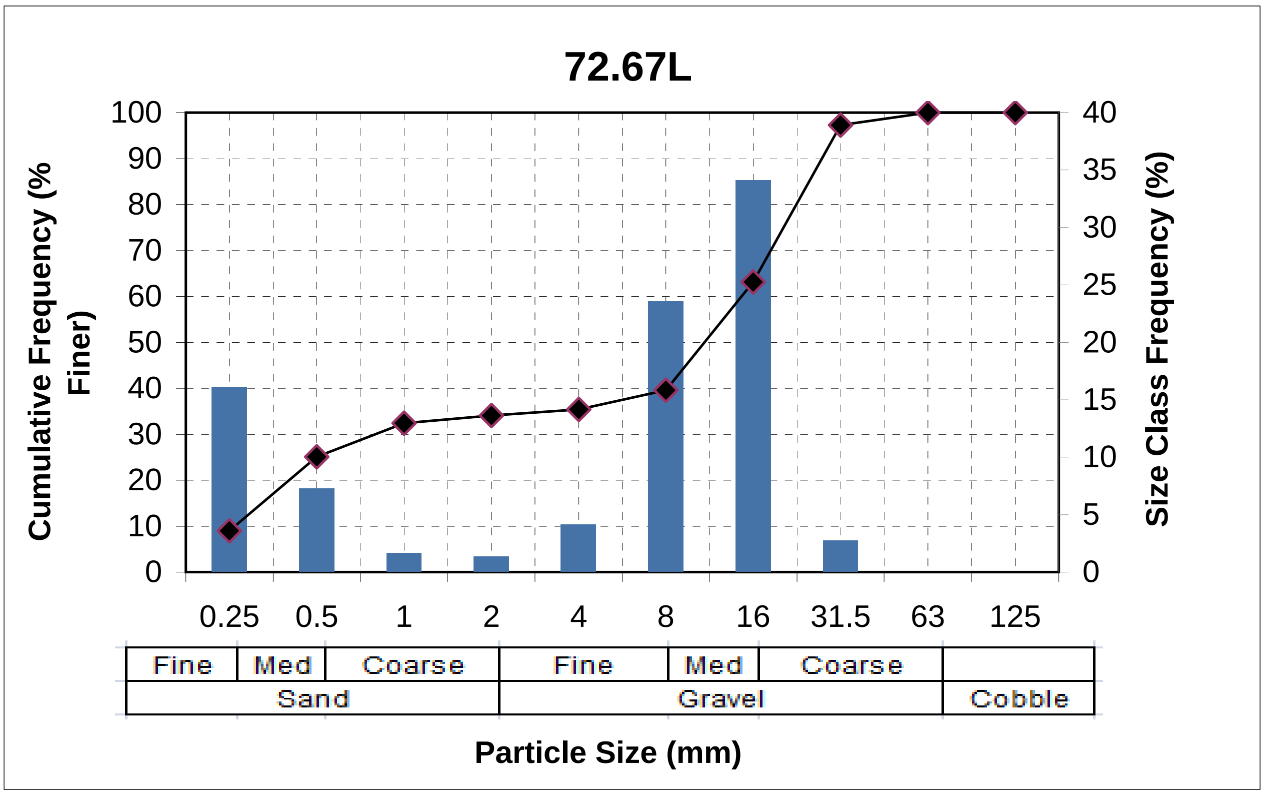


Figure C-49. Patch 72.71L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	100.0	0.0	0
16	53.2	46.8	1659
8	23.4	29.8	1058
4	20.5	2.9	102
2	19.9	0.6	21
1	18.8	1.1	38
0.5	12.2	6.6	233
0.25	3.8	8.4	299
Pan	---	3.8	135
Total			3545

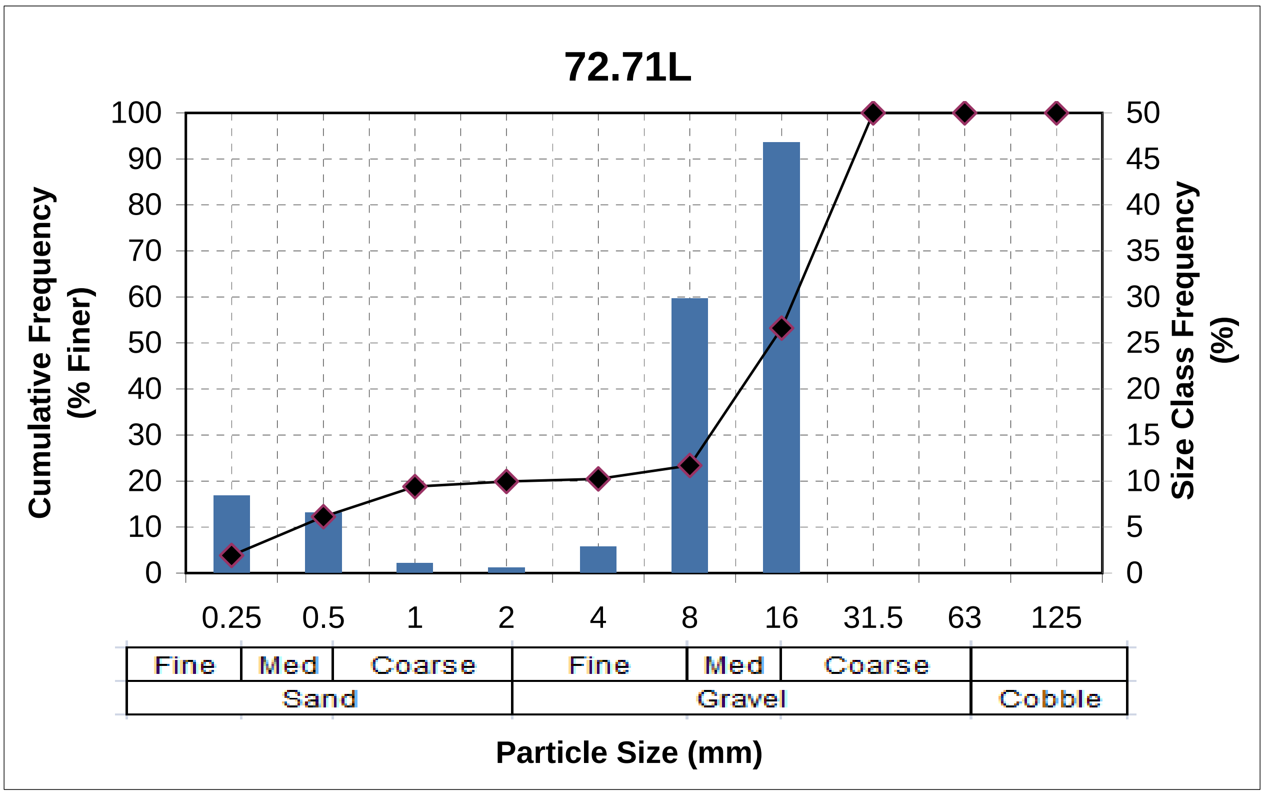


Figure C-50. Patch 72.73L Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	78.2	21.8	898
31.5	70.2	7.9	326
16	55.3	15.0	616
8	44.8	10.5	432
4	41.4	3.4	139
2	37.0	4.4	181
1	31.7	5.3	216
0.5	23.6	8.2	336
0.25	7.3	16.2	668
Pan	---	7.3	302
Total			4114

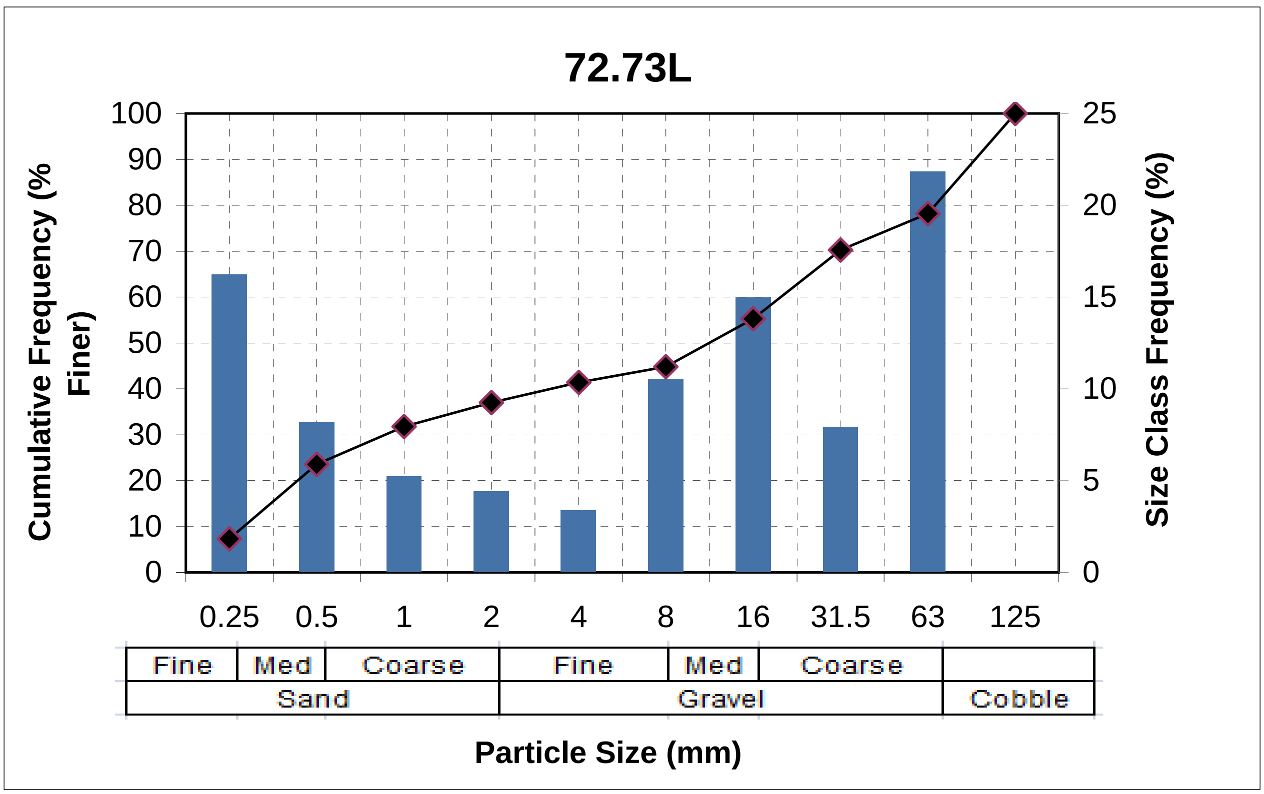


Figure C-51. Patch 73.18R Gravel Size and Percentage (n=1).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	95.3	4.7	178
16	55.4	39.9	1507
8	36.6	18.8	709
4	30.1	6.5	245
2	23.8	6.3	239
1	15.6	8.2	311
0.5	7.1	8.5	322
0.25	1.5	5.6	211
Pan	---	1.5	56
Total			3778

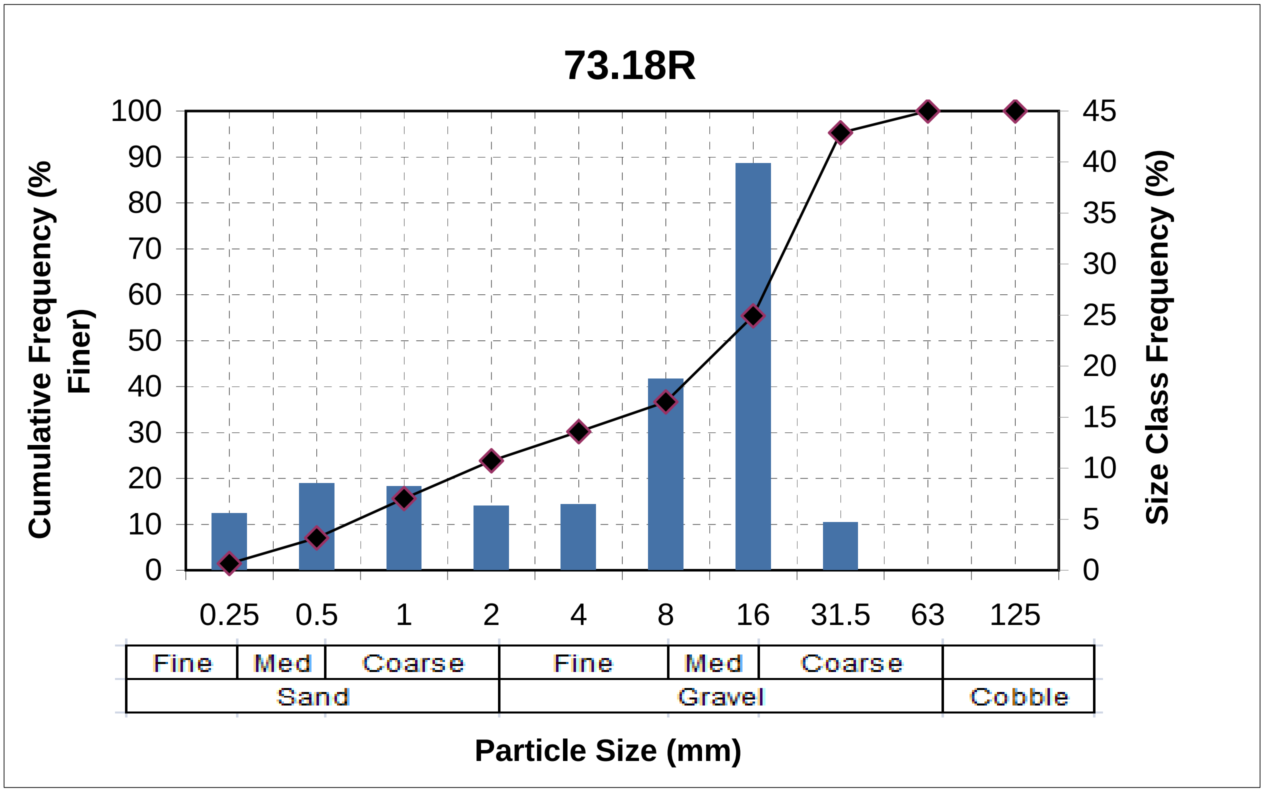


Figure C-52. Patch 73.25L Gravel Size and Percentage (n=3).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	95.0	5.0	564
16	78.3	16.7	1886
8	63.2	15.0	1694
4	50.3	12.9	1453
2	28.0	22.4	2519
1	17.1	10.9	1223
0.5	5.9	11.2	1264
0.25	1.5	4.4	492
Pan	---	1.5	174
Total			11269

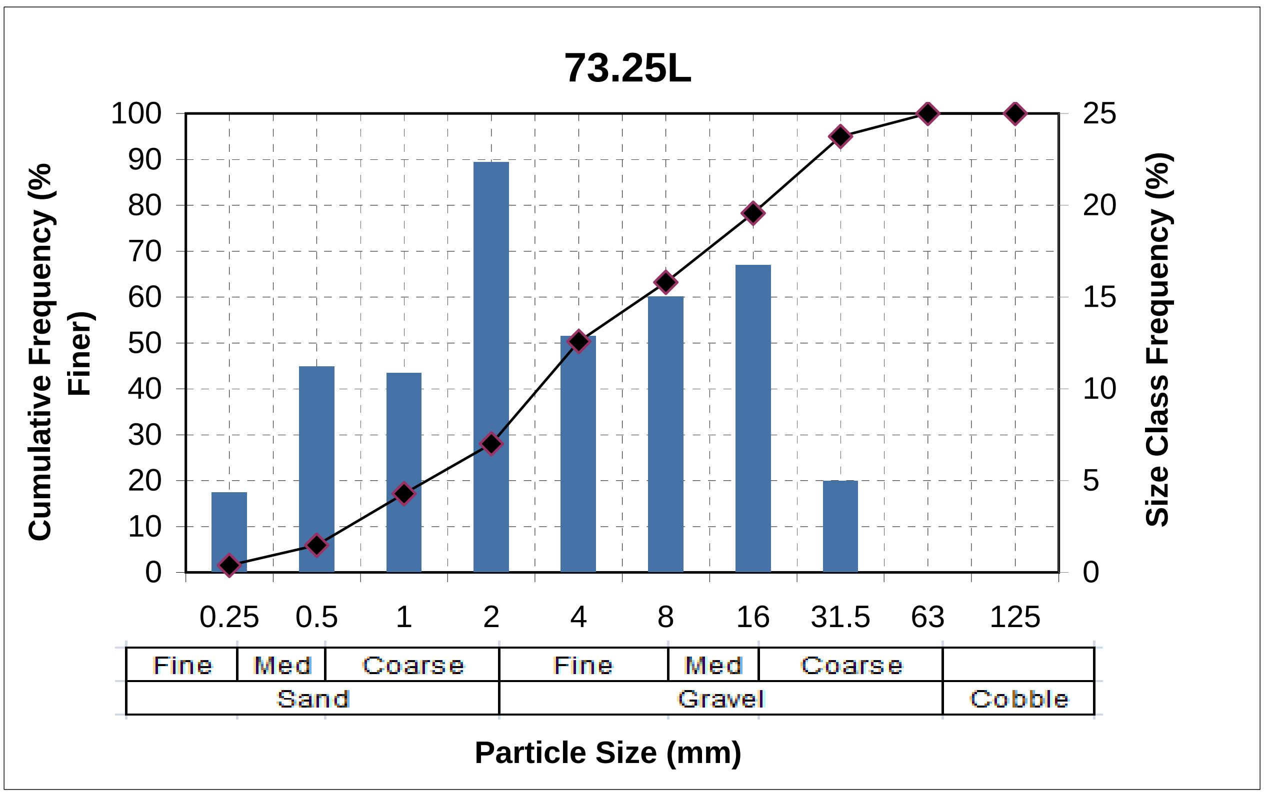


Figure C-53. Patch 73.43L Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	100.0	0.0	0
16	81.0	19.0	370
8	46.6	34.4	672
4	31.4	15.3	298
2	23.8	7.5	147
1	17.9	5.9	116
0.5	10.6	7.3	143
0.25	4.7	5.9	115
Pan	---	4.7	91
Total			1952

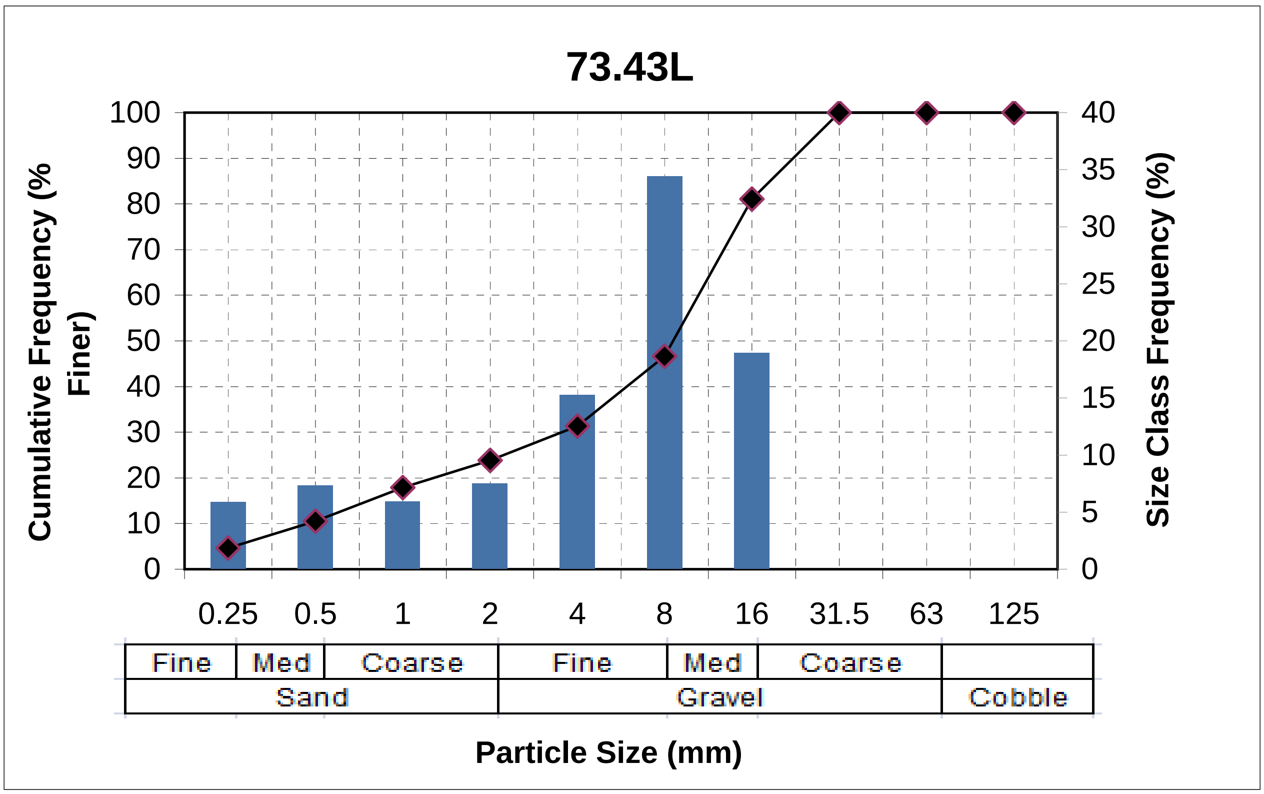


Figure C-54. Patch 73.49L Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	79.1	20.9	403
16	53.6	25.4	490
8	38.2	15.5	298
4	28.7	9.5	183
2	21.0	7.6	147
1	15.7	5.3	103
0.5	9.4	6.3	121
0.25	3.1	6.3	122
Pan	---	3.1	59
Total			1926

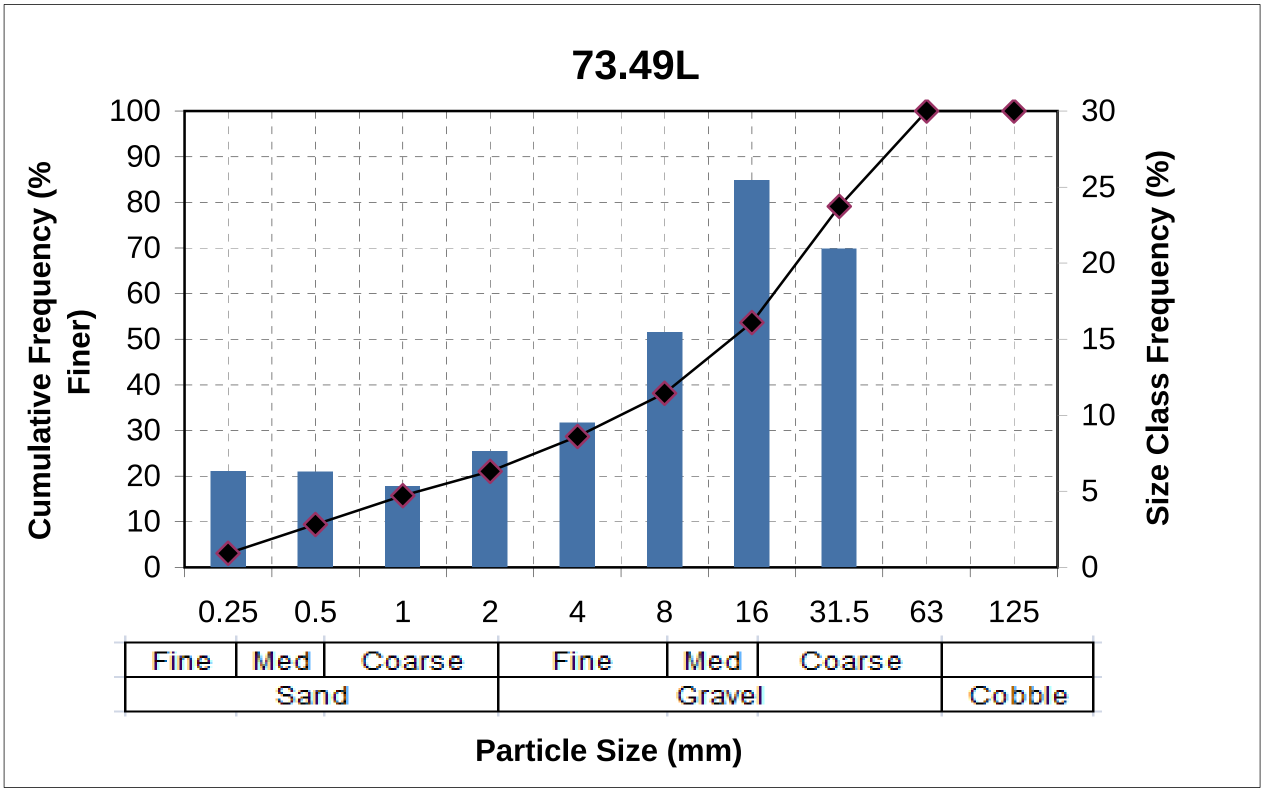


Figure C-55. Patch 73.54R Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	86.3	13.7	790
16	55.0	31.3	1800
8	36.2	18.8	1080
4	24.7	11.5	662
2	17.9	6.8	392
1	12.7	5.2	300
0.5	7.9	4.8	279
0.25	4.1	3.7	215
Pan	---	4.1	238
Total			5756

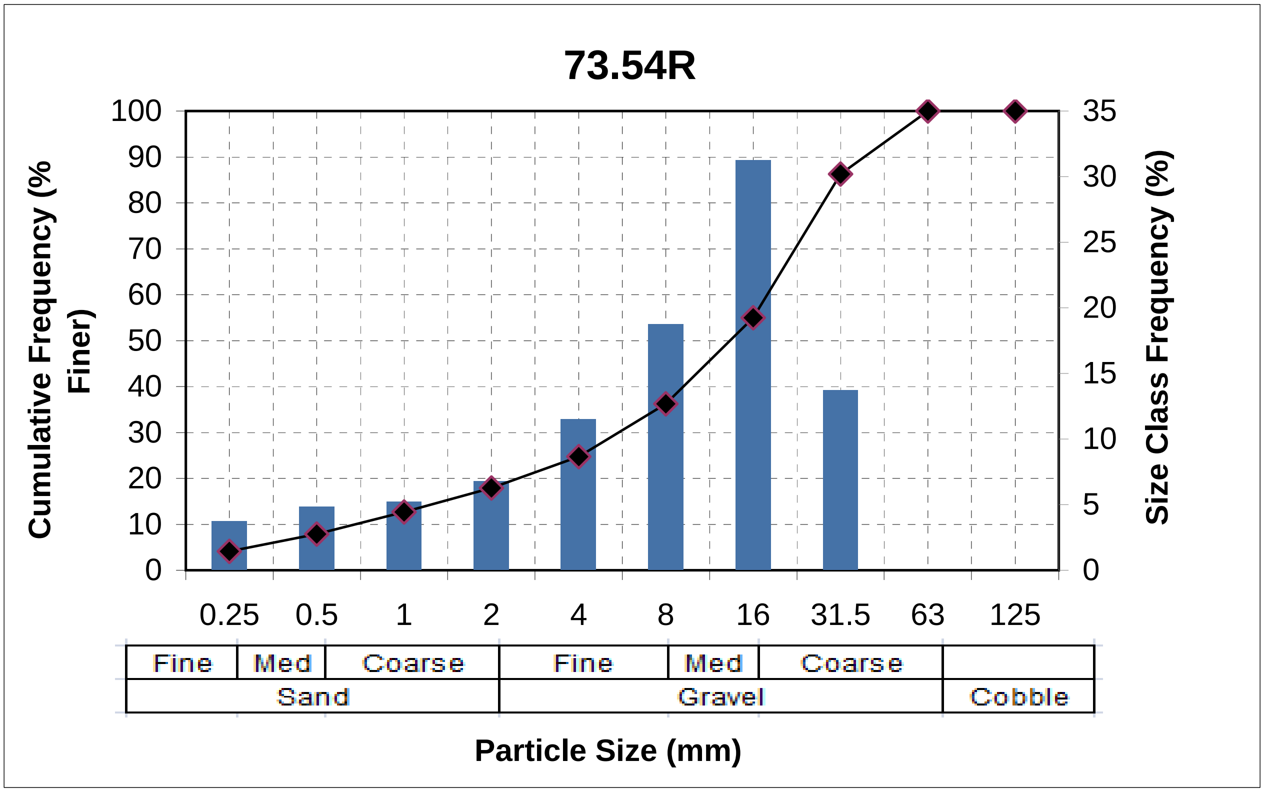


Figure C-56. Patch 73.58L Gravel Size and Percentage (n=2).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	100.0	0.0	0
31.5	89.5	10.5	199
16	55.8	33.7	640
8	29.8	26.1	495
4	20.0	9.8	186
2	12.8	7.2	136
1	6.7	6.2	117
0.5	2.2	4.5	85
0.25	0.5	1.7	32
Pan	---	0.5	10
Total			1900

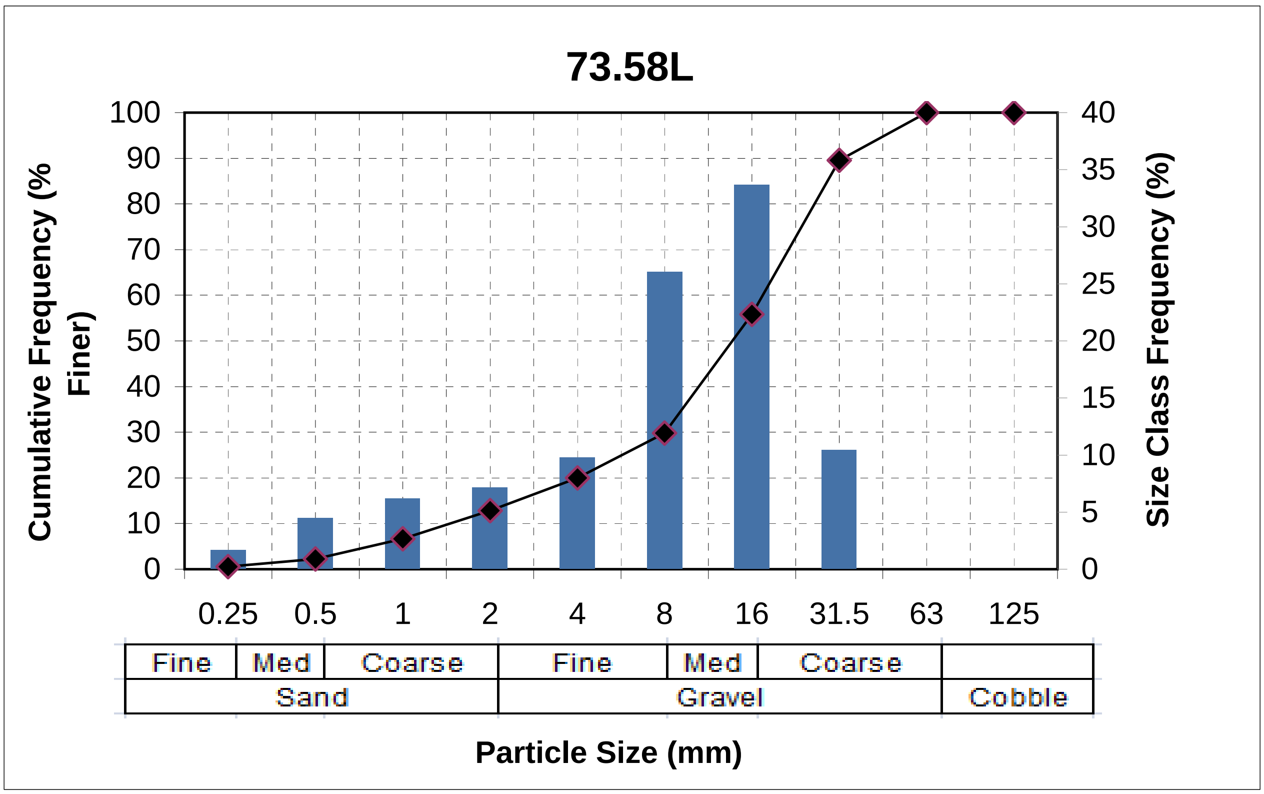


Figure C-57. Patch 73.63R Gravel Size and Percentage (n=3).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	94.1	5.9	612
31.5	88.1	5.9	612
16	63.8	24.3	2503
8	35.9	27.9	2877
4	20.2	15.6	1609
2	16.3	3.9	401
1	13.4	3.0	304
0.5	8.4	5.0	510
0.25	3.2	5.2	535
Pan	---	3.2	332
Total			10295

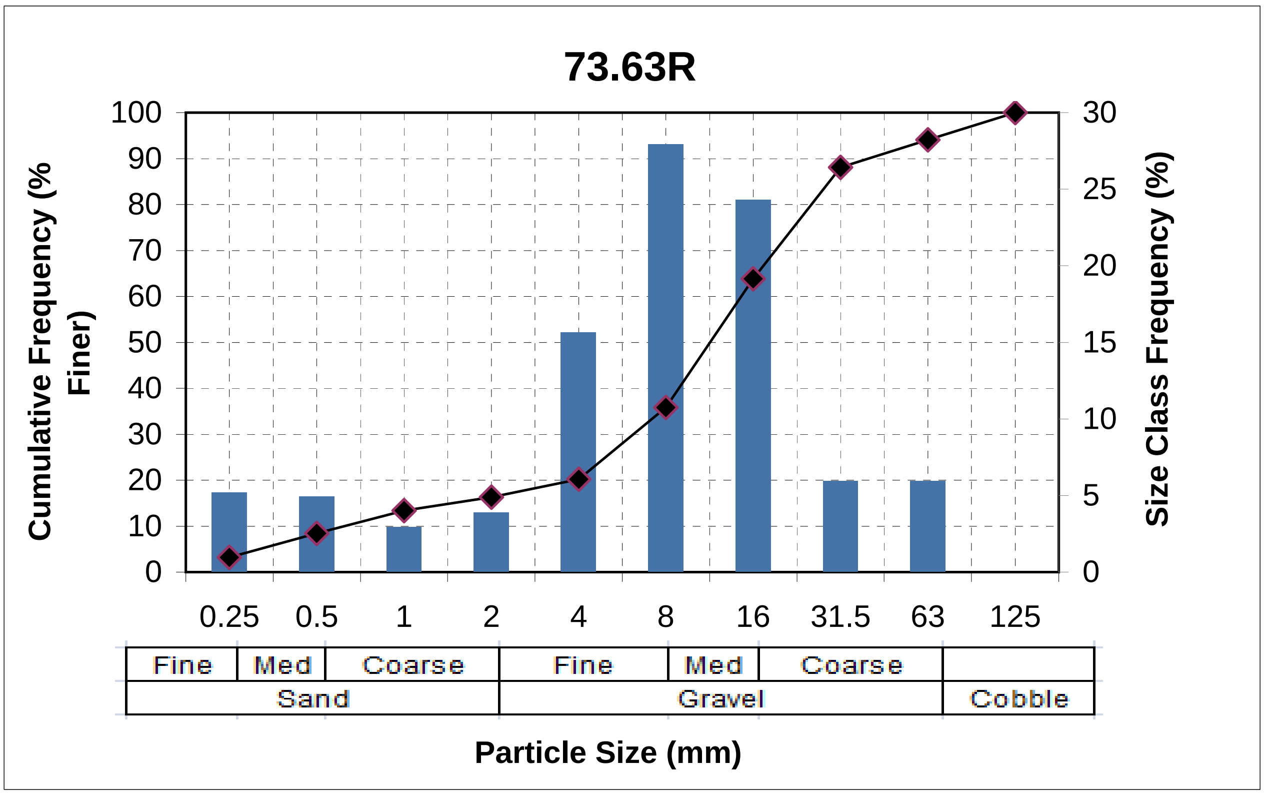
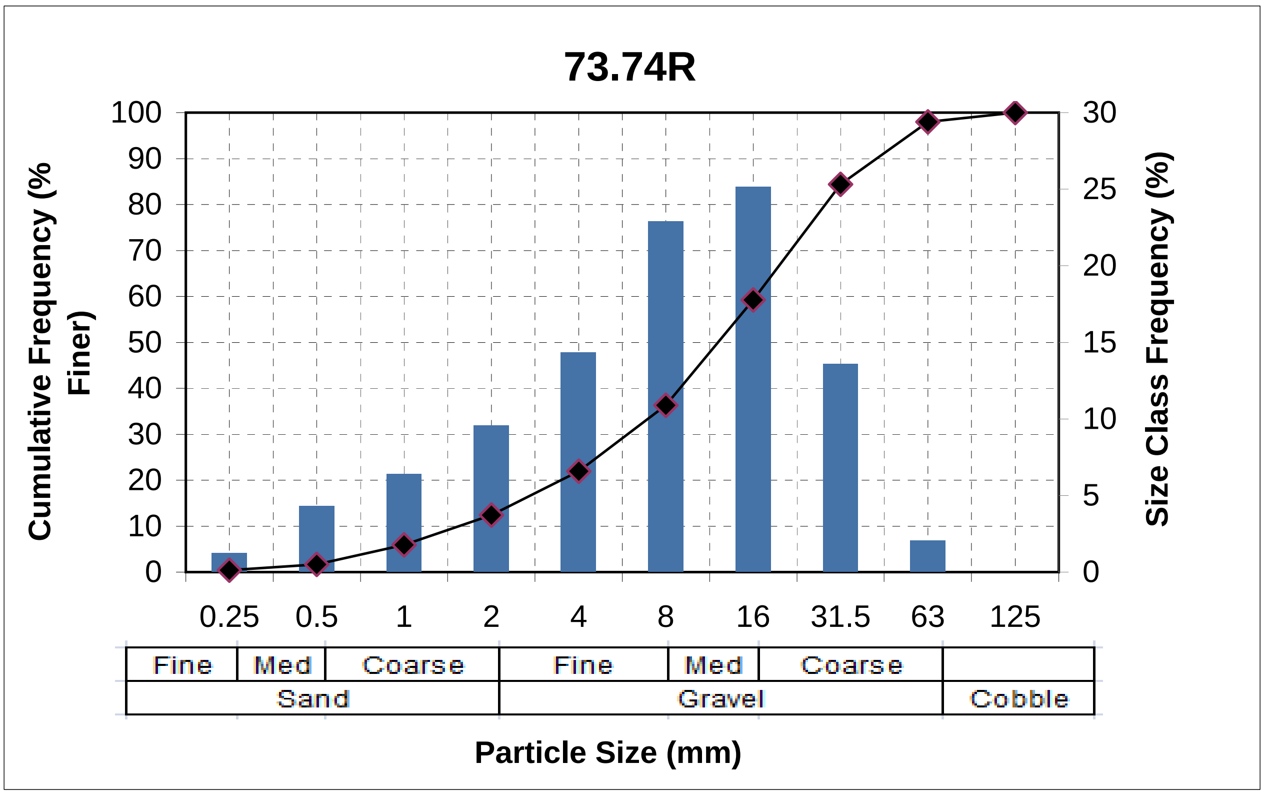


Figure C-58. Patch 73.74R Gravel Size and Percentage (n=6).

Particle size (mm)	Percent Finer (%)	Size Class Frequency (%)	Sample Mass Retained (g)
125	100.0	0.0	0
63	98.0	2.0	380
31.5	84.4	13.6	2533
16	59.2	25.2	4686
8	36.3	22.9	4267
4	21.9	14.4	2676
2	12.4	9.6	1783
1	6.0	6.4	1197
0.5	1.7	4.3	801
0.25	0.4	1.3	235
Pan	---	0.4	73
Total			18631



APPENDIX D

Spawning Patch Stage-Discharge Relationships

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Table D-1. Spawning Patch Details.

Spawning Patch ID	River Mile	River Bank	Site Location	Patch Number	Stage-Discharge Regression Constants: a	b	Stage at Zero Flow	Elevation (cfs): Avg	Max	Min
Monroe Street Bridge	**73.88**									
73.74R	73.74	Right		58	342.0	2.5	1730.5	3204	11387	0
73.63R	73.63	Right		57	15.2	3.1	1727.8	3399	9017	1395
73.58L	73.58	Left		56	388.1	1.8	1724.6	1362	2631	765
73.54R	73.54	Right		55	847.7	1.5	1718.2	7005	10868	4113
73.49L	73.49	Left		54	801.4	1.5	1722.5	6757	10769	4554
Maple Street Bridge	**73.45**									
73.43L	73.43	Left	Peaceful Valley	53	850.6	1.4	1718.4	1324	1666	1102
73.25L	73.25	Left		52	167.8	2.0	1716.1	4372	9434	847
73.18R	73.18	Right		51	288.6	1.8	1716.5	2278	2806	1302
--	73.10	Right		--	--	--	--	--	--	--
72.73L	72.73	Left		50	488.3	1.8	1715.4	8443	11227	6194
72.71L	72.71	Left		49	84.4	2.6	1718.2	7879	13908	3247
72.67L	72.67	Left		48	565.4	1.9	1716.0	10285	17493	6398
72.56L	72.56	Left		47	343.1	1.9	1711.7	6574	8560	3870
72.53L	72.53	Left		46	375.6	1.9	1713.7	0	0	0
Sandifur Memorial Bridge	**72.46**									
72.47L	72.47	Left		45	324.5	1.8	1710.1	407	1244	169
72.42R	72.42	Right		44	48.0	2.6	1708.2	0	459	0
72.24R	72.24	Right		43	71.6	2.6	1705.6	6596	10820	1515
Hangman (Latah) Creek	**72.20**									
72.19R	71.91	Right		42	243.5	1.9	1702.3	4067	6610	1081
71.74L	71.74	Left		41	50.0	2.4	1697.6	5213	5587	4773
71.71L	71.71	Left		40	134.5	2.1	1697.7	6453	7524	5323
71.69L	71.69	Left		39	607.1	1.6	1698.6	3086	5498	2235
71.66L	71.66	Left		38	68.1	2.3	1695.5	2682	3924	2028
71.52R	71.52	Right	Upper San Souci	37	233.5	1.9	1694.9	4827	5843	3724
71.3L	71.30	Left		36	316.3	1.8	1693.9	14084	16915	8535
71.26L	71.26	Left		35	50.0	2.3	1686.9	10587	11835	9233
71.23L	71.23	Left		34	495.3	1.5	1690.8	7197	7999	6434
70.88R	70.88	Right	San Souci	33	51.6	2.4	1681.7	13135	15857	10854
70.83R	70.83	Right		32	416.2	1.7	1686.7	10225	10835	9472
70.77R	70.77	Right		31	151.9	2.1	1684.9	5727	8149	4111
70.65R	70.65	Right	Lower San Souci	30	174.3	2.0	1684.5	1860	2345	1484
70.39L	70.39	Left		29	787.3	1.6	1687.7	2469	2640	2316
70.35L	70.35	Left		28	213.9	2.2	1684.0	5019	6599	3745
70.28R	70.28	Right		27	822.9	1.6	1686.8	6078	10194	3530
70.27L	70.27	Left		26	1000.0	1.5	1686.8	14523	26110	8192
70.26R	70.26	Right		25	1000.0	1.6	1683.7	8986	13910	3842
70.25L	70.25	Left		24	629.0	1.6	1684.9	6668	8239	4251
70.2L	70.20	Left		23	207.1	2.0	1680.8	2721	5917	1045
70.18R	70.18	Right		22	99.5	2.4	1684.0	8345	8708	7484
70.17L	70.17	Left		21	122.6	2.2	1677.8	9060	11610	5509
70.14L	70.14	Left		20	40.1	2.6	1681.0	7494	8306	6239
T.J. Meenach Springs	**70.13**									
70.13R	70.13	Right		19	90.1	2.4	1685.3	5543	7273	3114
70.06L	70.06	Left		18	300.0	2.9	1679.4	1611	5193	422
70.04R	70.04	Right		17	50.0	2.6	1678.2	6377	16435	982
70.03L	70.03	Left		16	300.0	2.8	1685.5	1701	2523	634
69.96L	69.96	Left		15	1000.0	1.5	1675.9	0	0	0
69.96R	69.96	Right		14	250.0	2.2	1674.2	6800	8649	4013
69.92L	69.92	Left		13	250.0	2.2	1677.0	4649	5832	3836
69.92R	69.92	Right		12	250.0	2.2	1677.7	3917	6665	2320
69.91L	69.91	Left		11	250.0	2.0	1675.7	2990	3396	2540
69.89L	69.89	Left		10	50.0	2.3	1671.9	2124	2683	1667
69.87L	69.87	Left		9	250.0	2.4	1681.0	601	842	480
T.J. Meenach Bridge	**69.81**									
69.79R	69.79	Right	Downriver Road	8	250.0	2.2	1676.0	10251	19156	2891
69.77R	69.77	Right		7	250.0	2.1	1674.3	1513	3147	608
69.72R	69.72	Right		6	250.0	1.9	1671.1	6630	12376	2964
68.35L	68.35	Left		5	250.0	1.8	1661.2	1009	3176	135
68.34L	68.34	Left		4	250.0	1.8	1661.1	7197	8634	6383
67.78L	67.78	Left		3	250.0	2.1	1658.5	422	485	349
Treatment Plant	**67.50 - 67.00**									
Bowl and Pitcher Park	**66.50 - 65.80**									
Swinging Bridge	**66.03**									
65.39R	65.39	Right		2	250.0	1.8	1626.2	7892	12114	5884
65.38R	65.38	Right		1	250.0	1.8	1627.5	9207	11397	7890

Figure D-1. Spawning Patch Stage Discharge Relationship at Patch 1 (65.38R) (top), Patch 2 (65.39R) (middle), and Patch 3 (67.78L) (bottom).

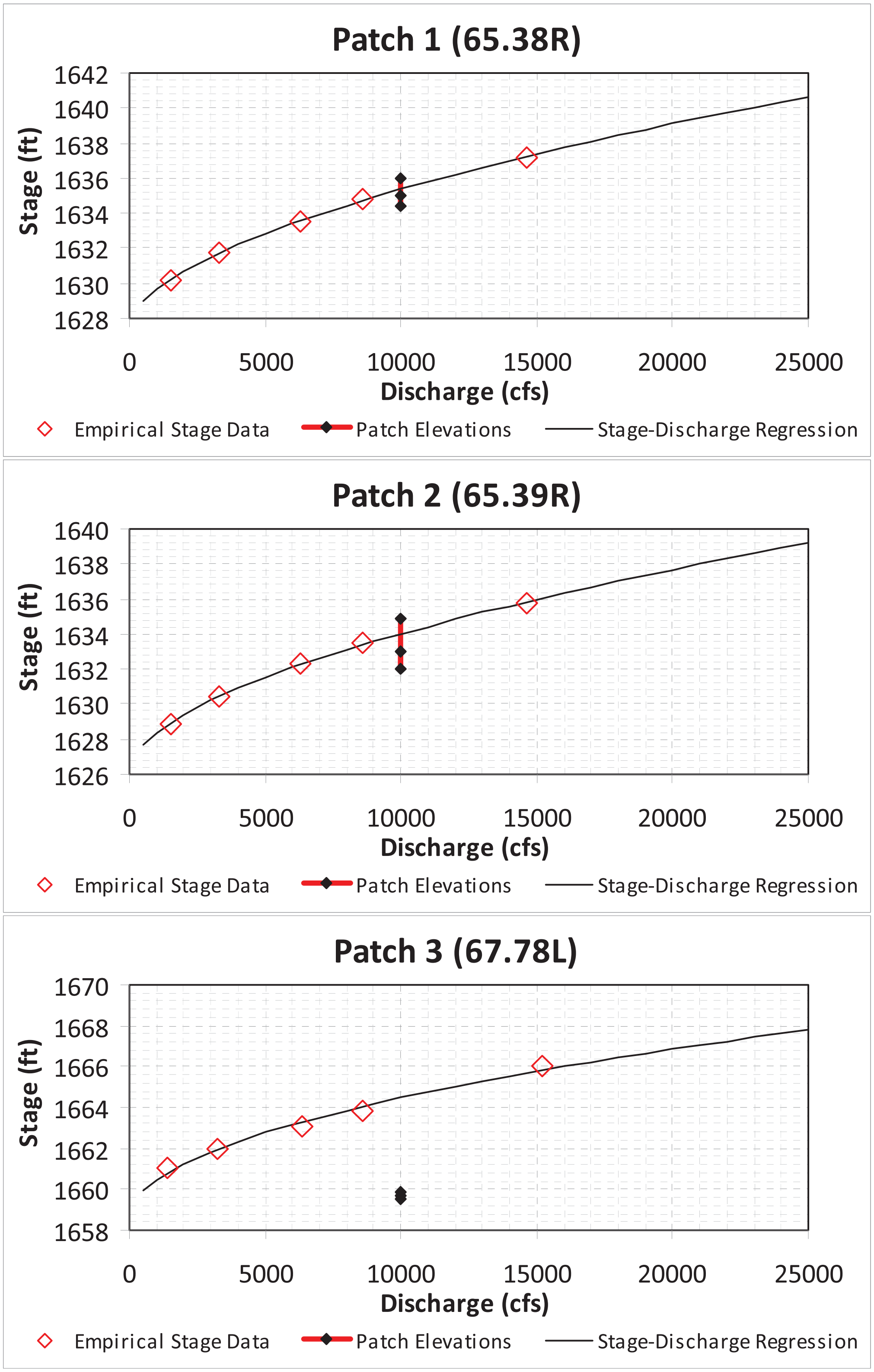
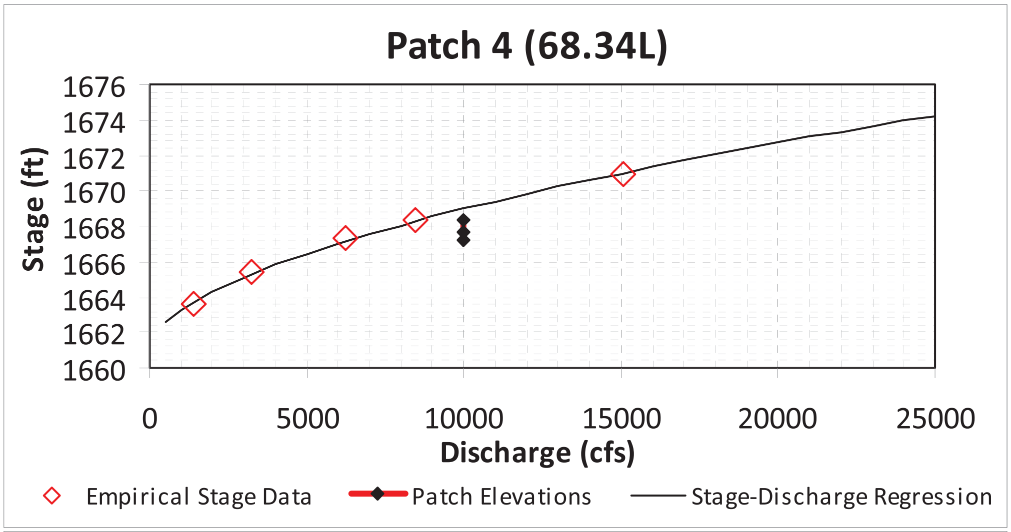
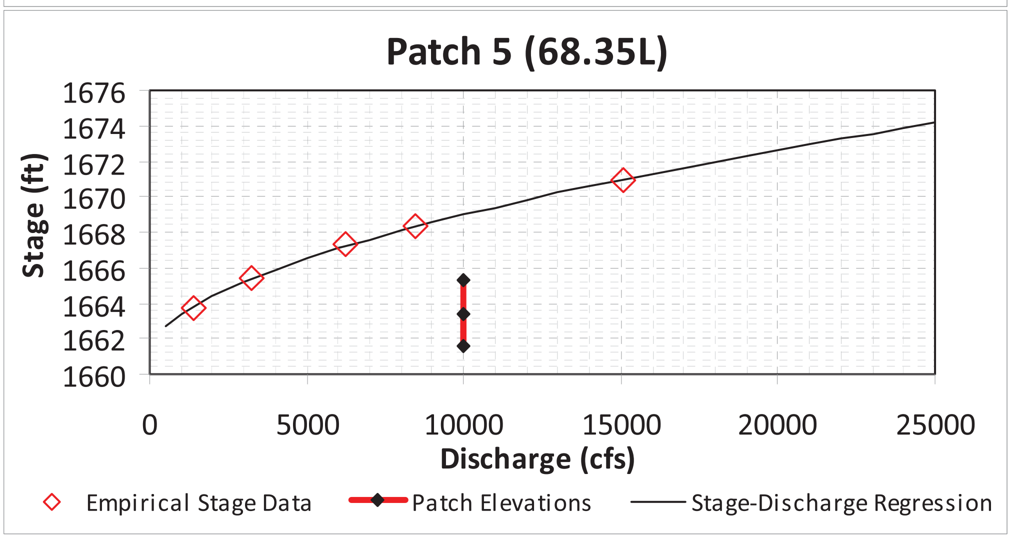


Figure D-2. Spawning Patch Stage Discharge Relationship at Patch 4 (68.34L) (top), Patch 5 (68.35L) (middle), and Patch 6 (69.72R) (bottom).





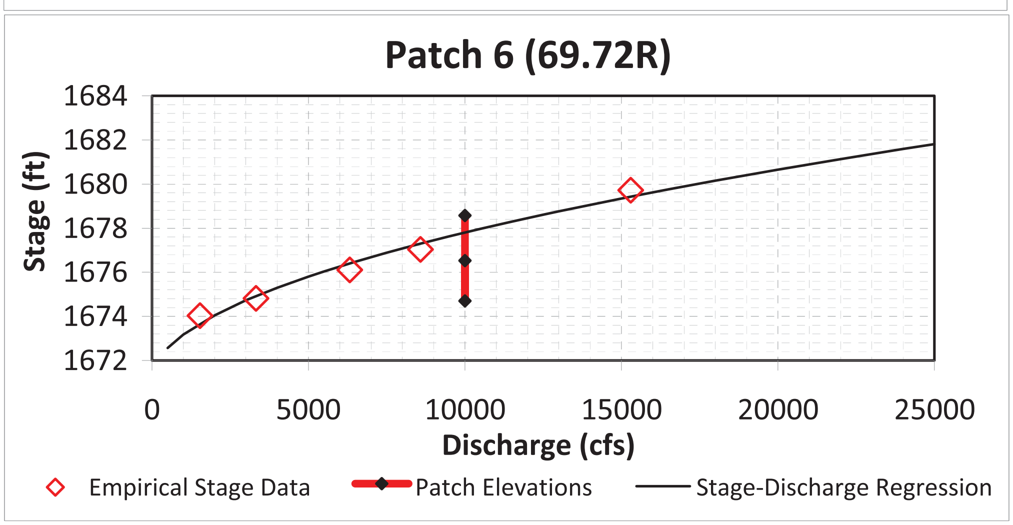
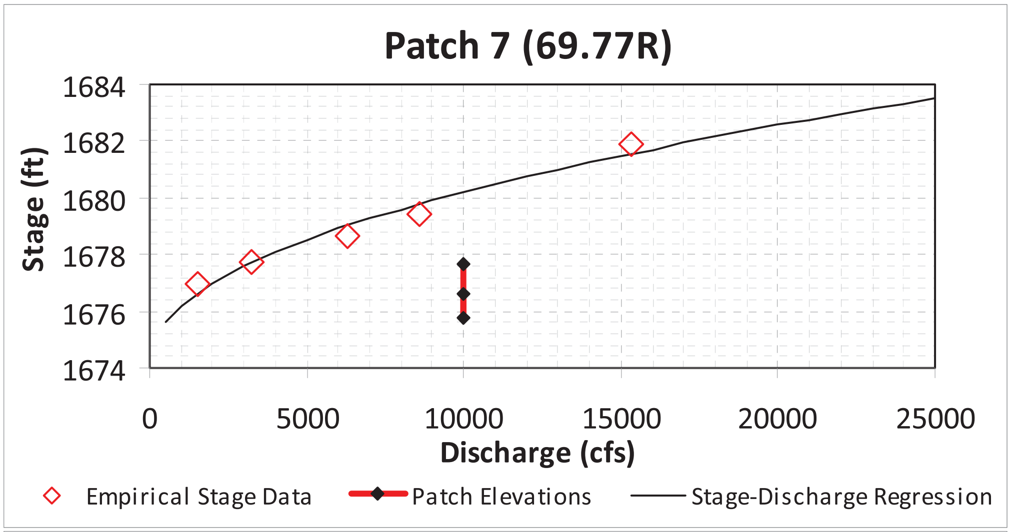
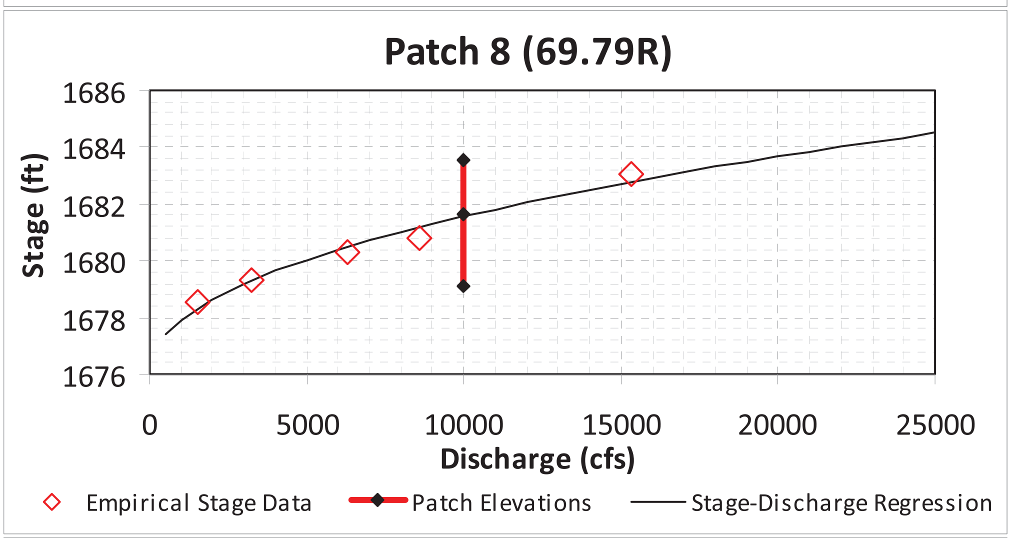


Figure D-3. Spawning Patch Stage Discharge Relationship at Patch 7 (69.77R) (top), Patch 8 (69.79R) (middle), and Patch 9 (69.87L) (bottom).





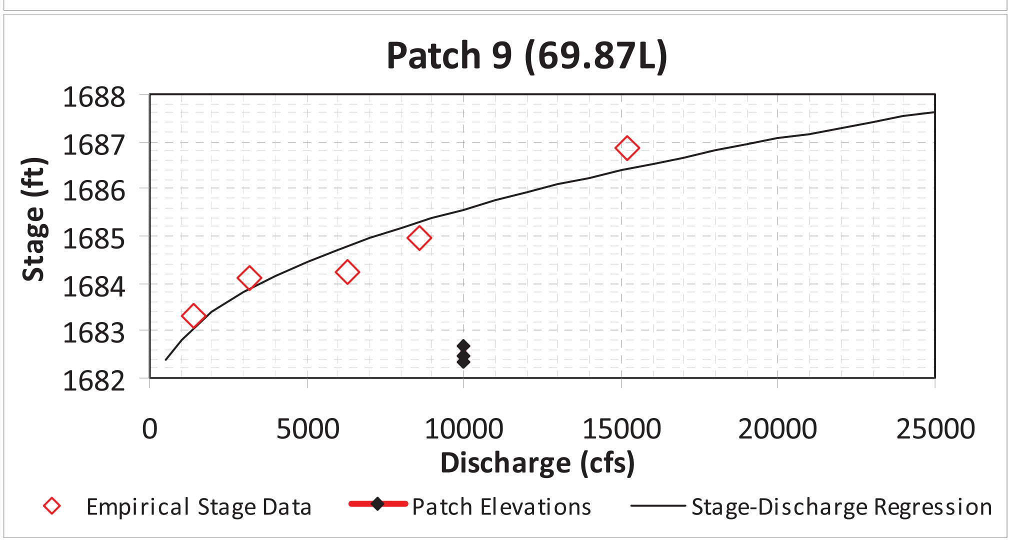
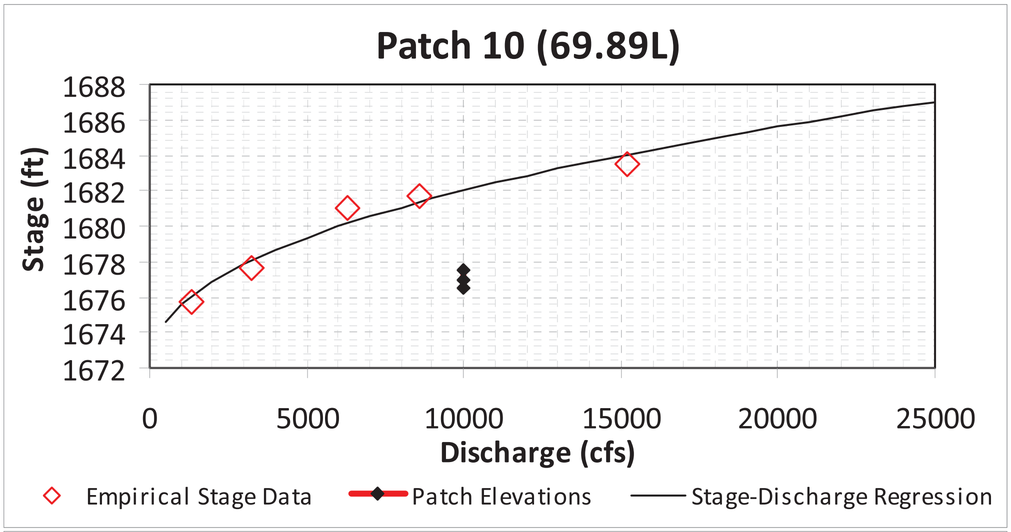
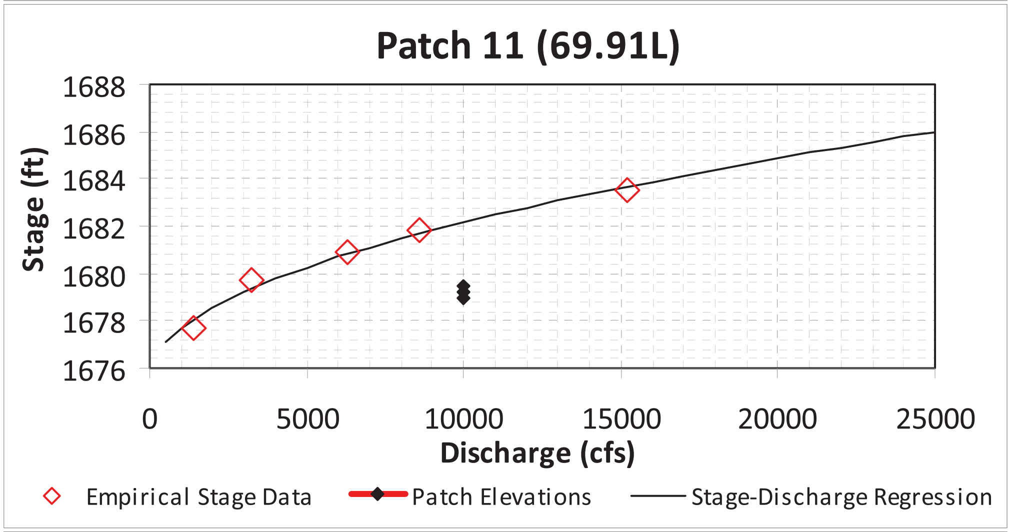


Figure D-4. Spawning Patch Stage Discharge Relationship at Patch 10 (69.89L) (top), Patch 11 (69.91L) (middle), and Patch 12 (69.92R) (bottom).





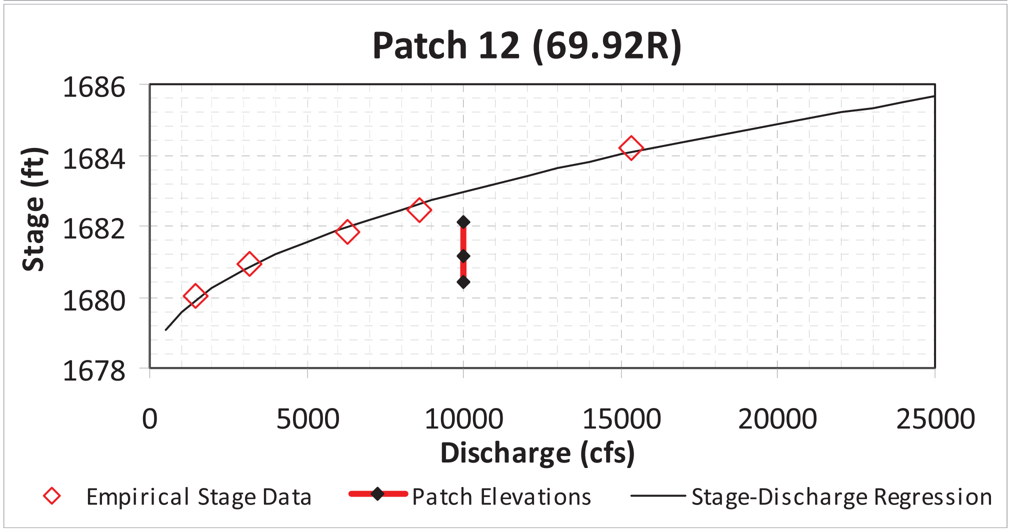
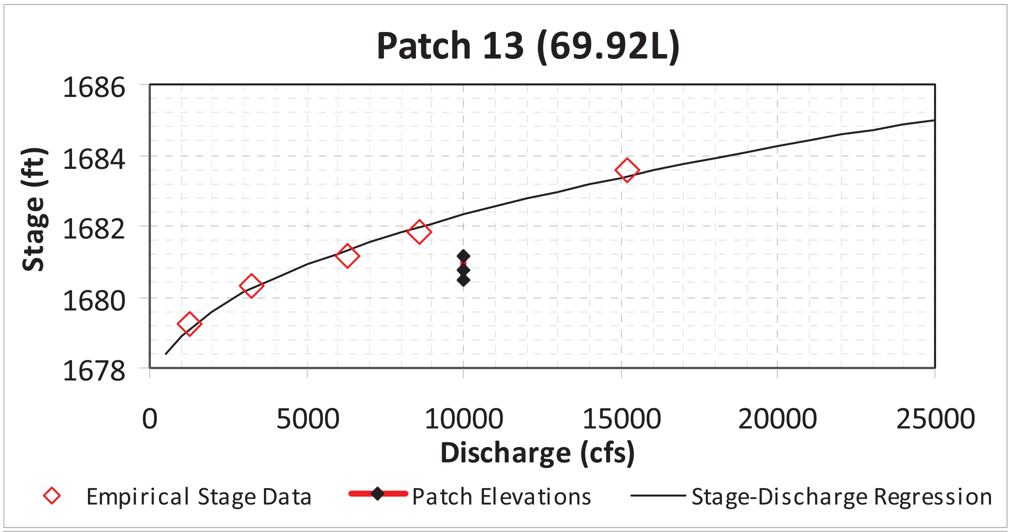
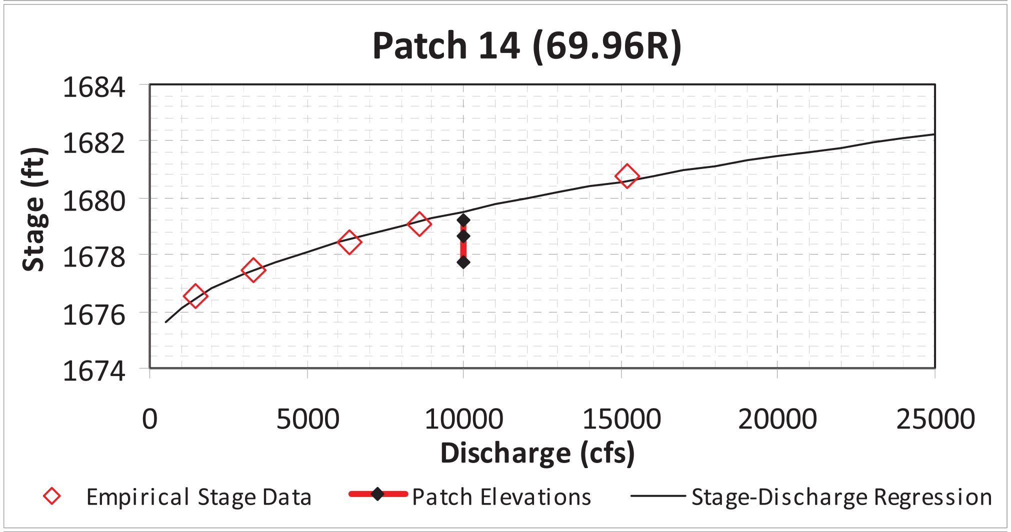


Figure D-5. Spawning Patch Stage Discharge Relationship at Patch 13 (69.92L) (top), Patch 14 (69.96R) (middle), and Patch 15 (69.96L) (bottom).





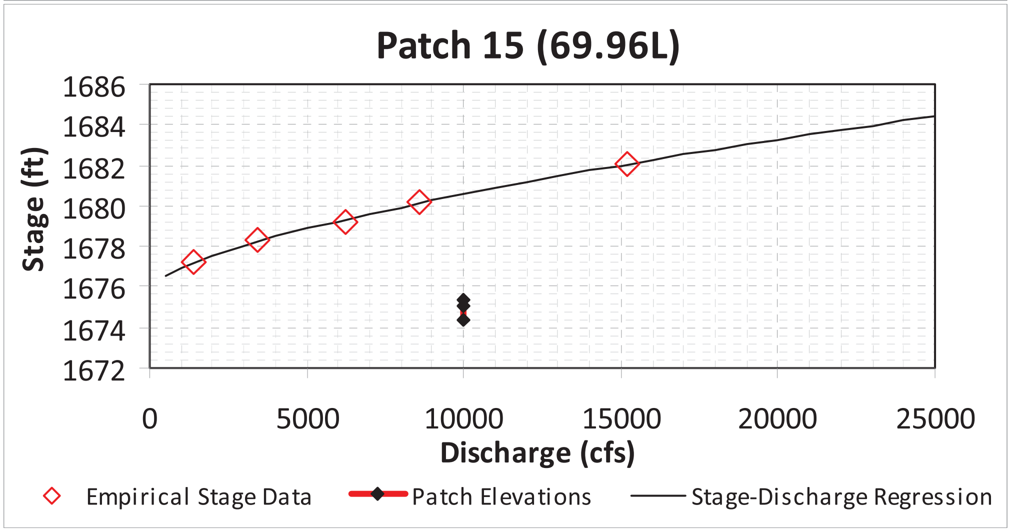
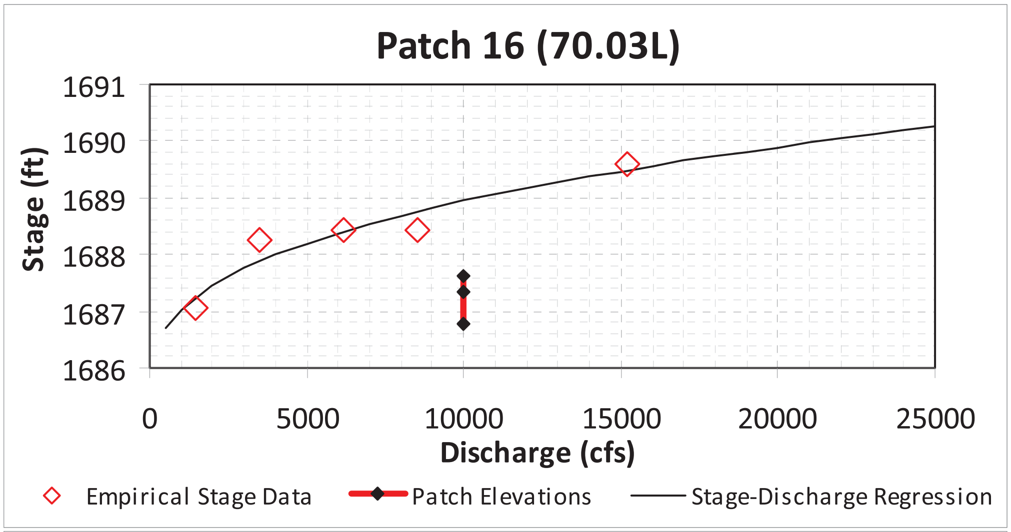
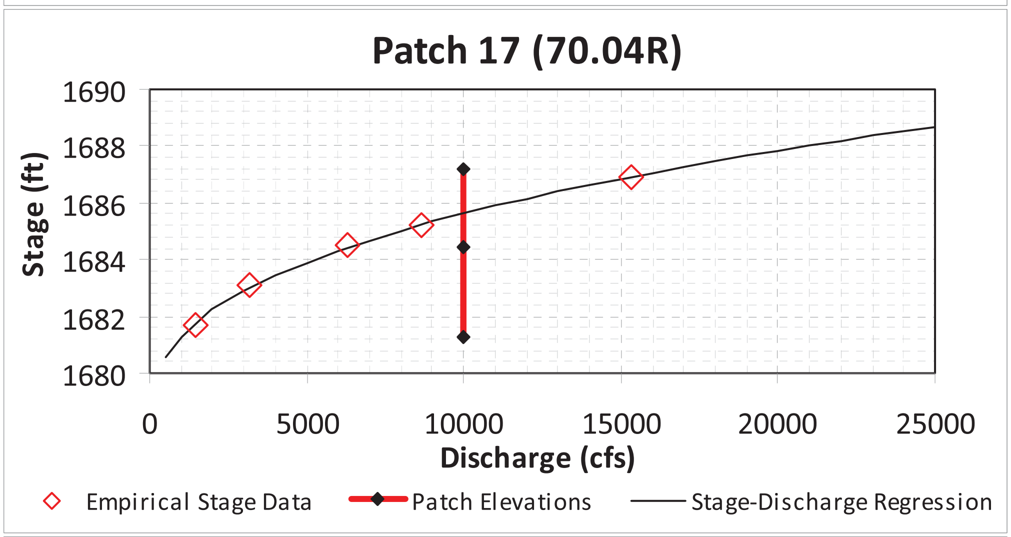


Figure D-6. Spawning Patch Stage Discharge Relationship at Patch 16 (70.03L) (top), Patch 17 (70.04R) (middle), and Patch 18 (70.06L) (bottom).





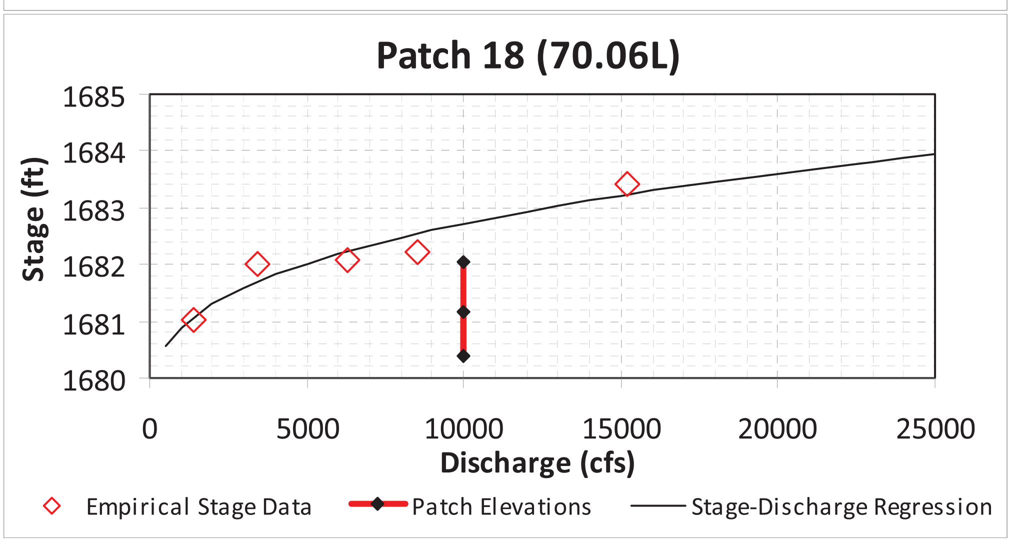
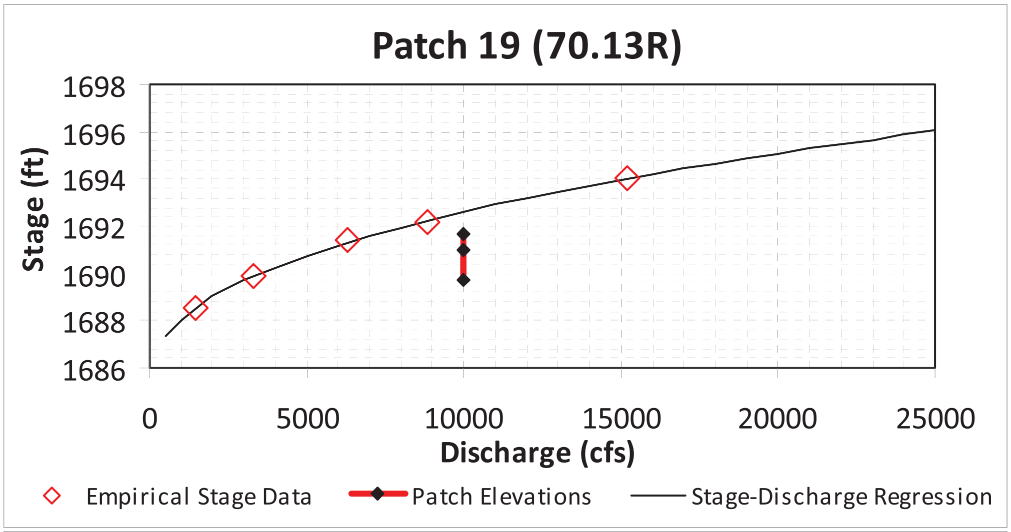
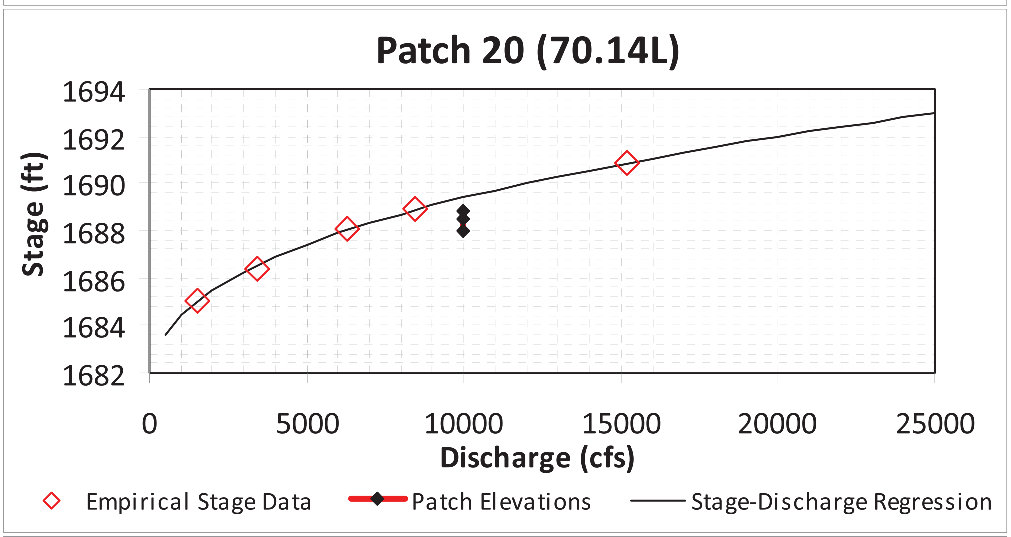


Figure D-7. Spawning Patch Stage Discharge Relationship at Patch 19 (70.13R) (top), Patch 20 (70.14L) (middle), and Patch 21 (70.17L) (bottom).





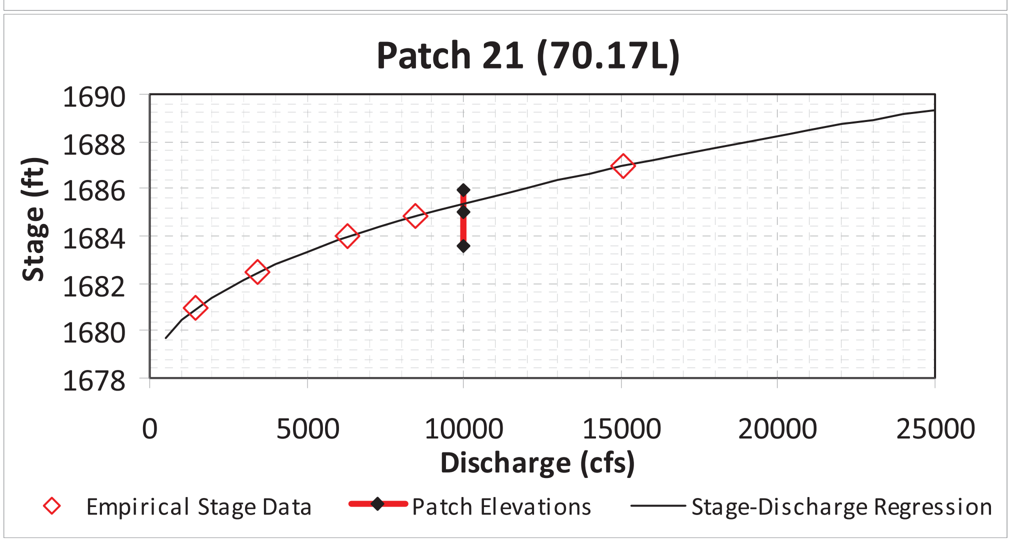
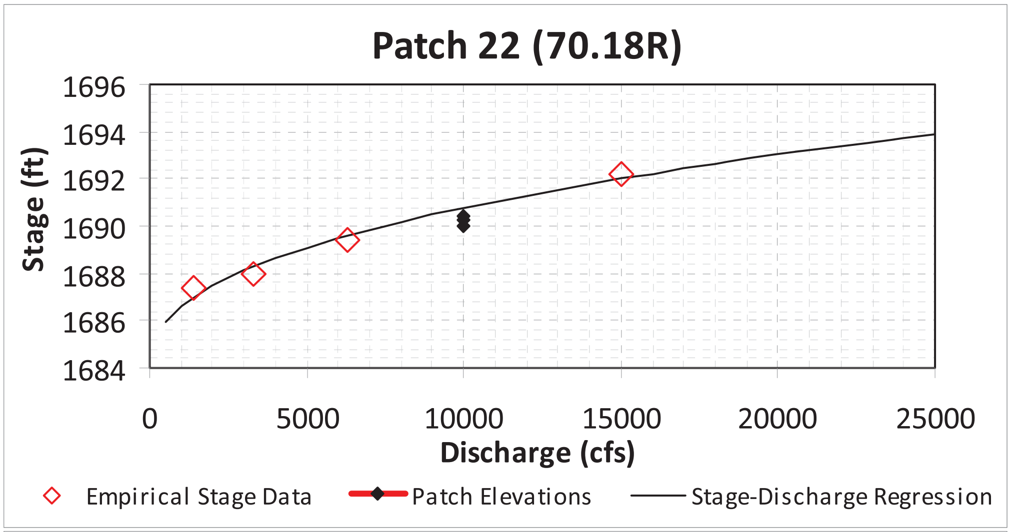
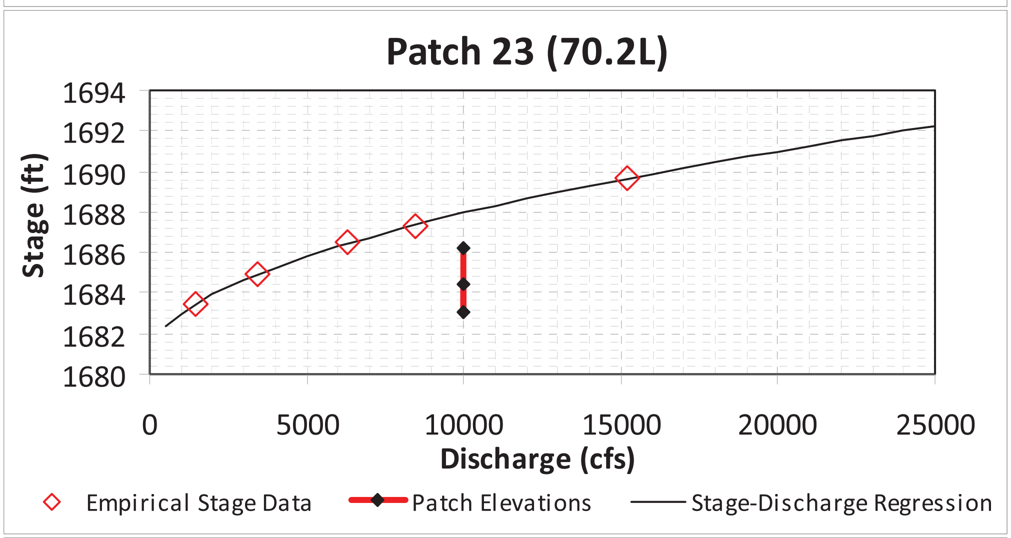
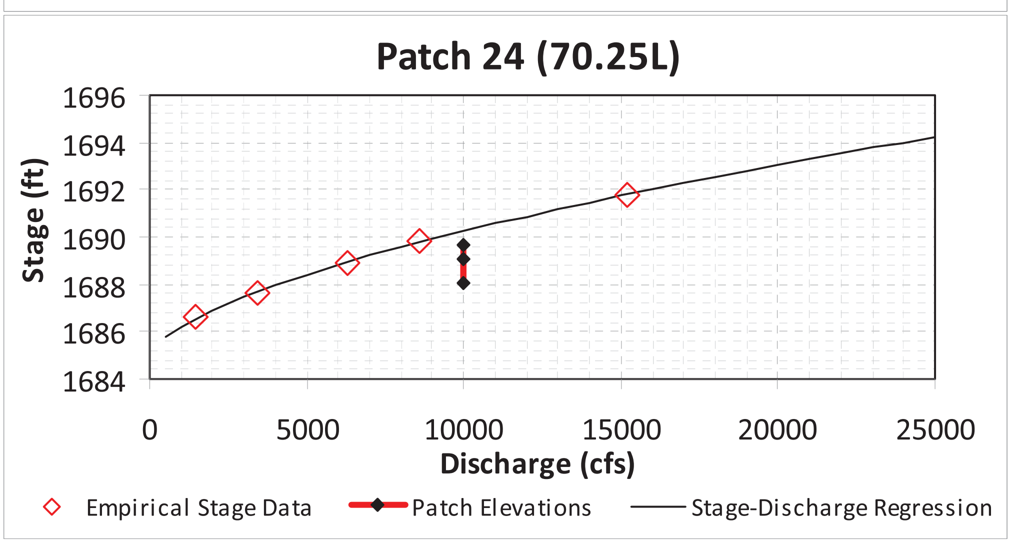


Figure D-8. Spawning Patch Stage Discharge Relationship at Patch 22 (70.18R) (top), Patch 23 (70.2L) (middle), and Patch 24 (70.25L) (bottom).







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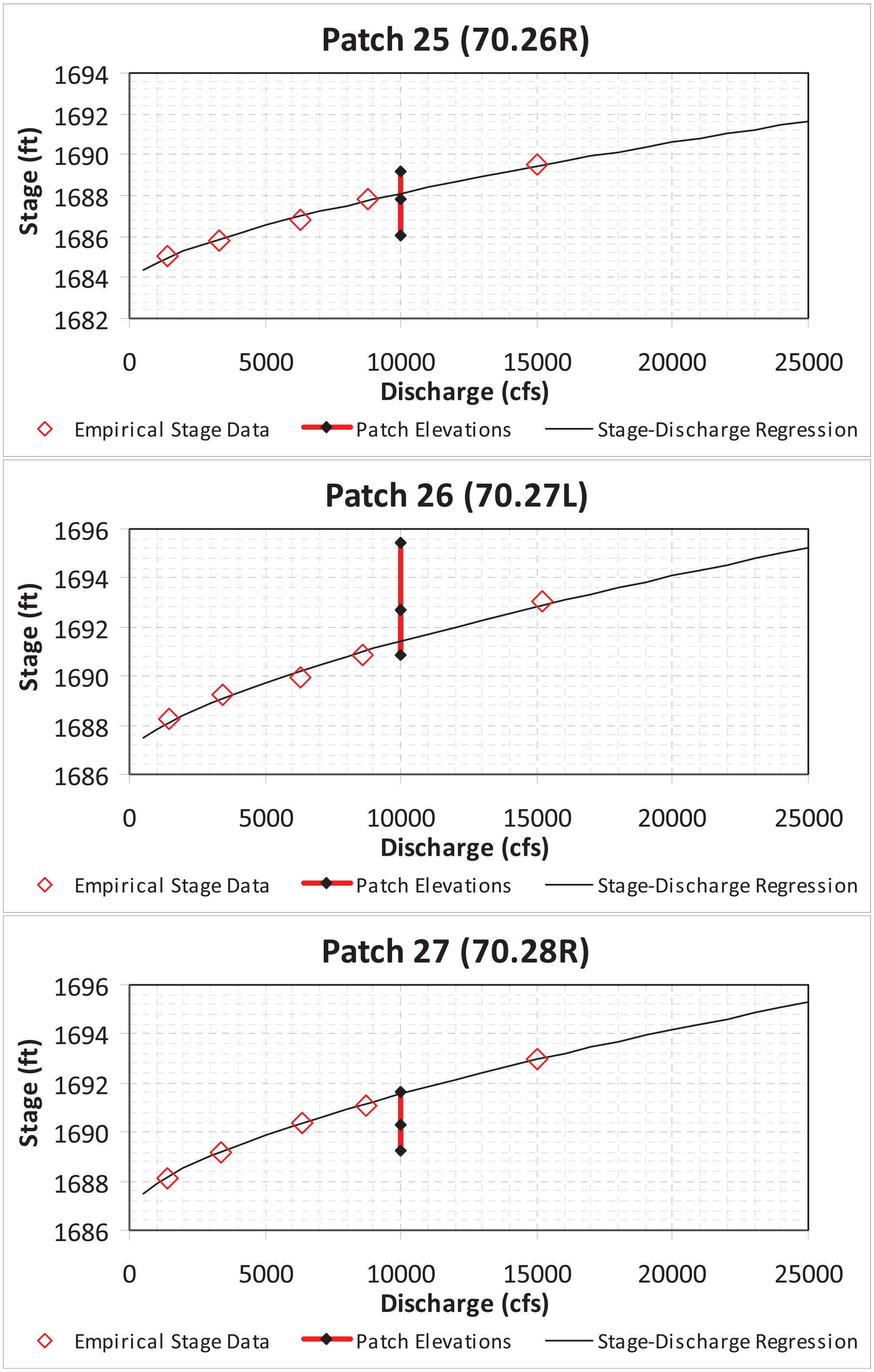
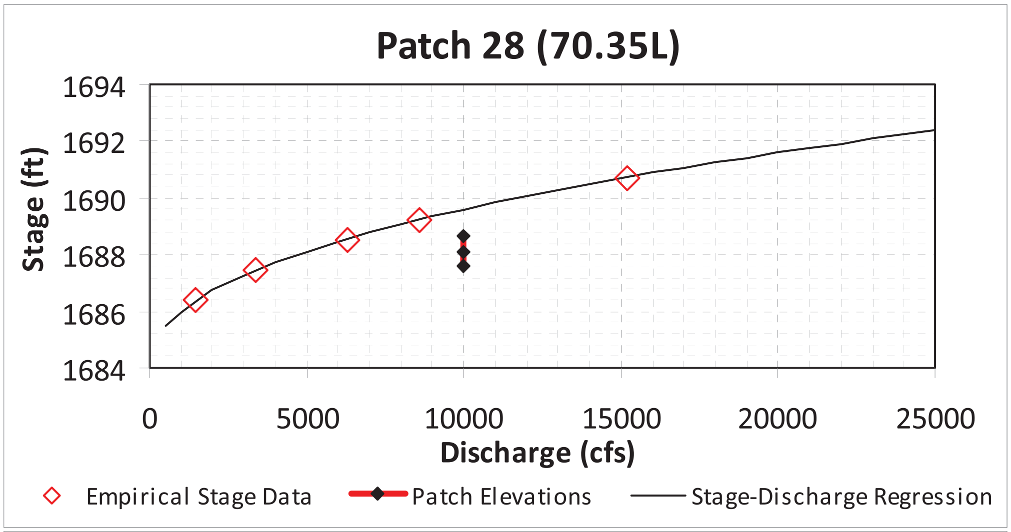
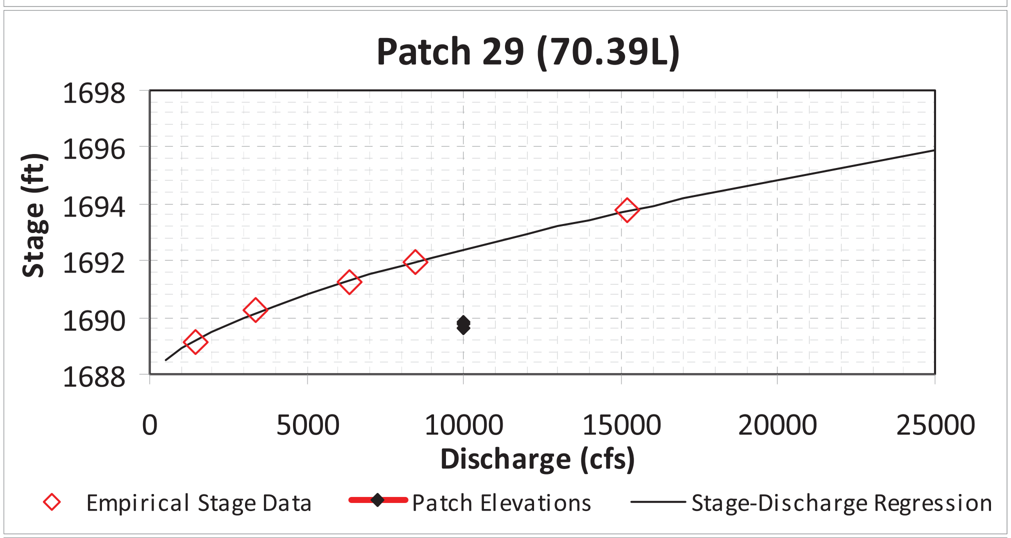


Figure D-10. Spawning Patch Stage Discharge Relationship at Patch 28 (70.35L) (top), Patch 29 (70.39L) (middle), and Patch 30 (70.65R) (bottom).





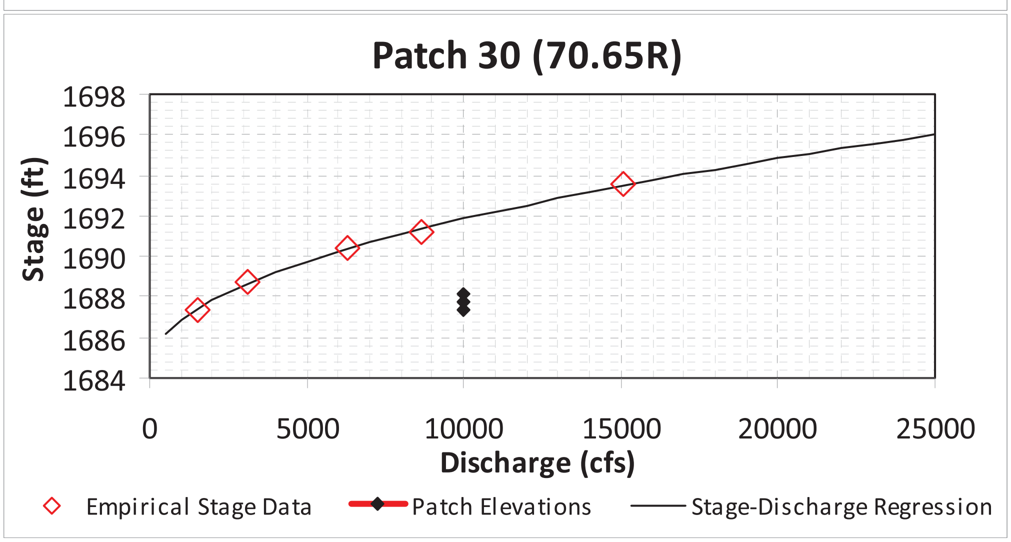
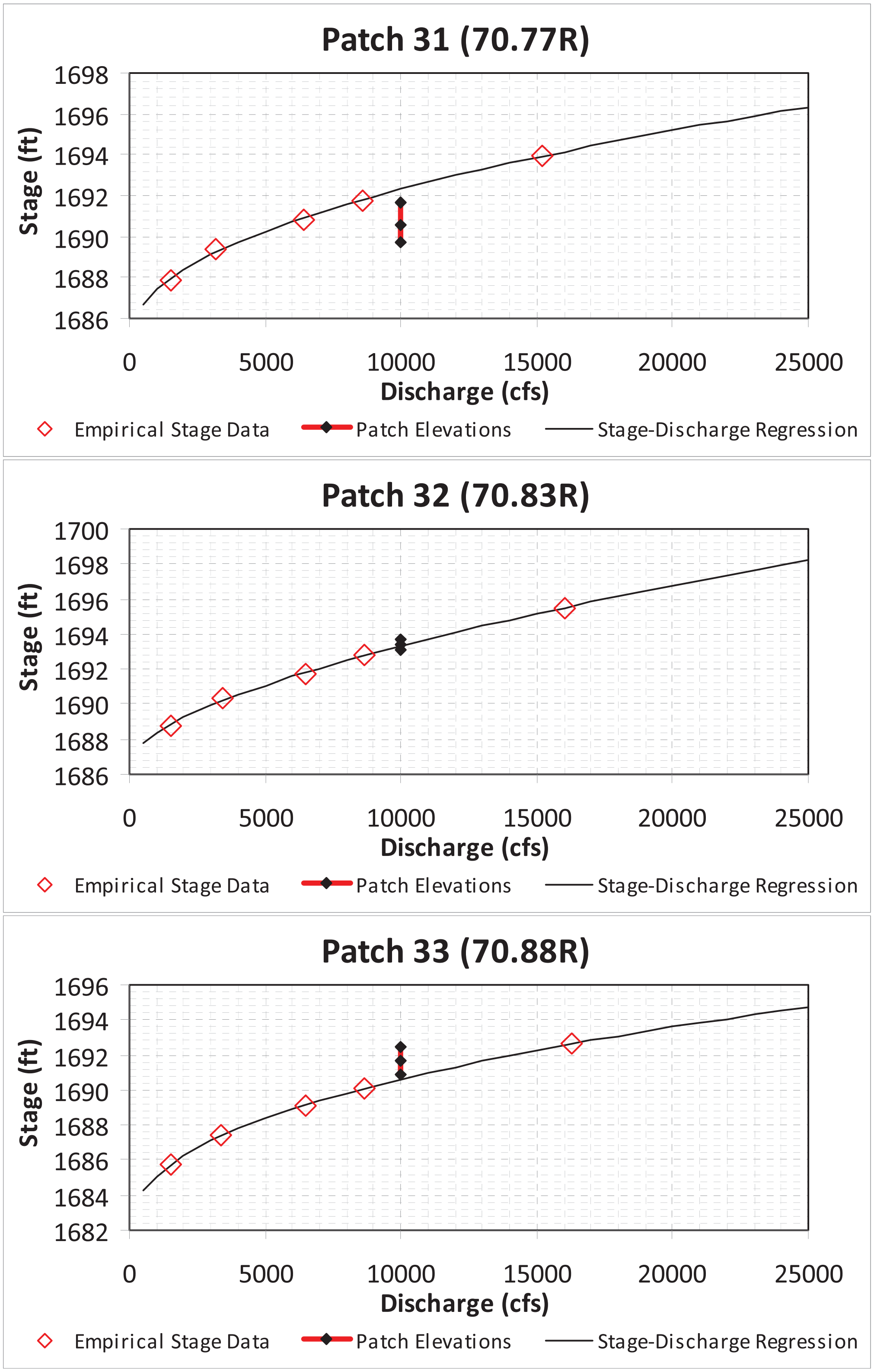


Figure D-11. Spawning Patch Stage Discharge Relationship at Patch 31 (70.77R) (top), Patch 32 (70.83R) (middle), and Patch 33 (70.88R) (bottom).



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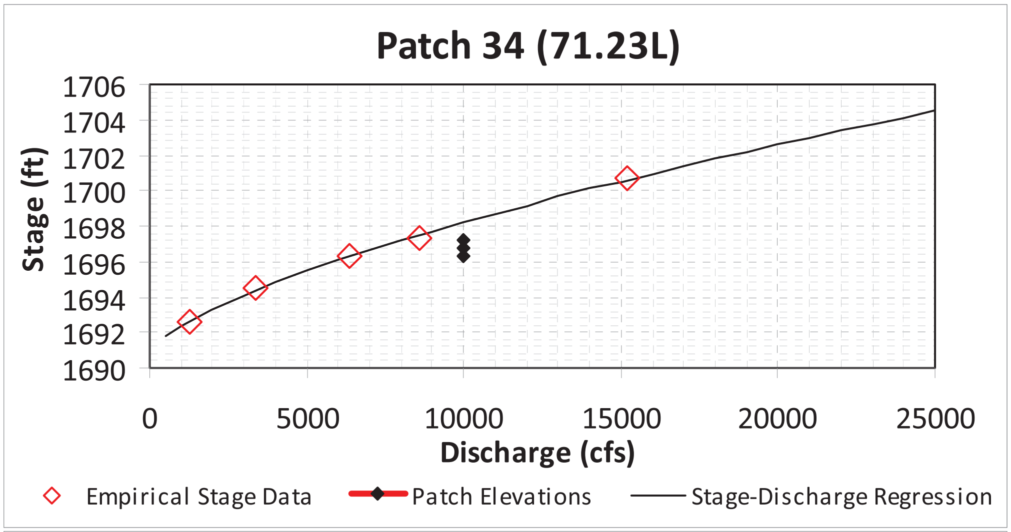
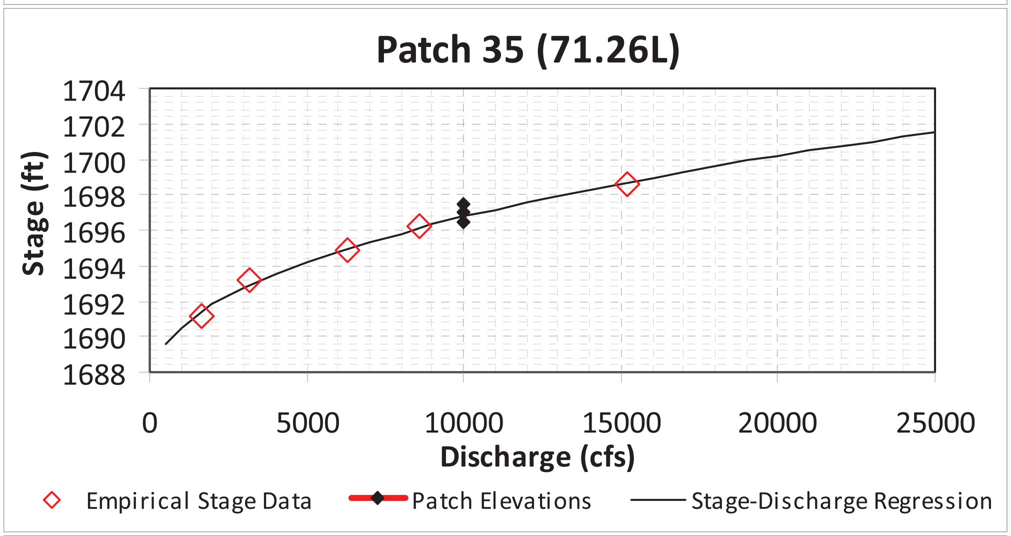




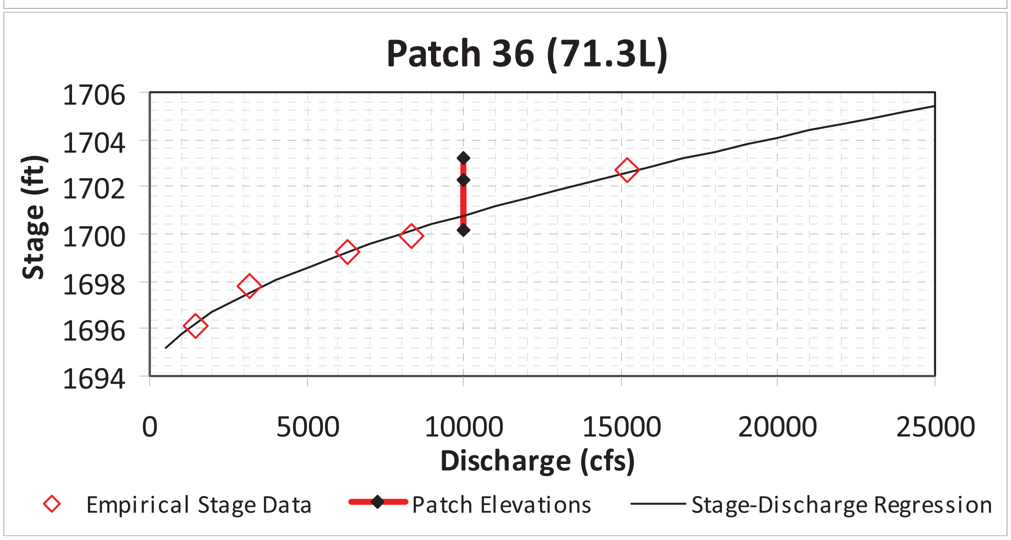
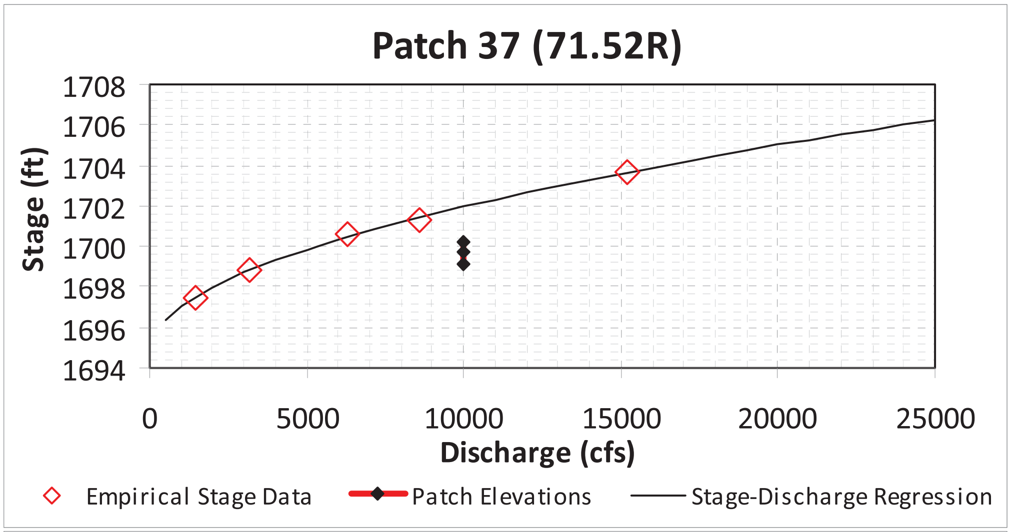
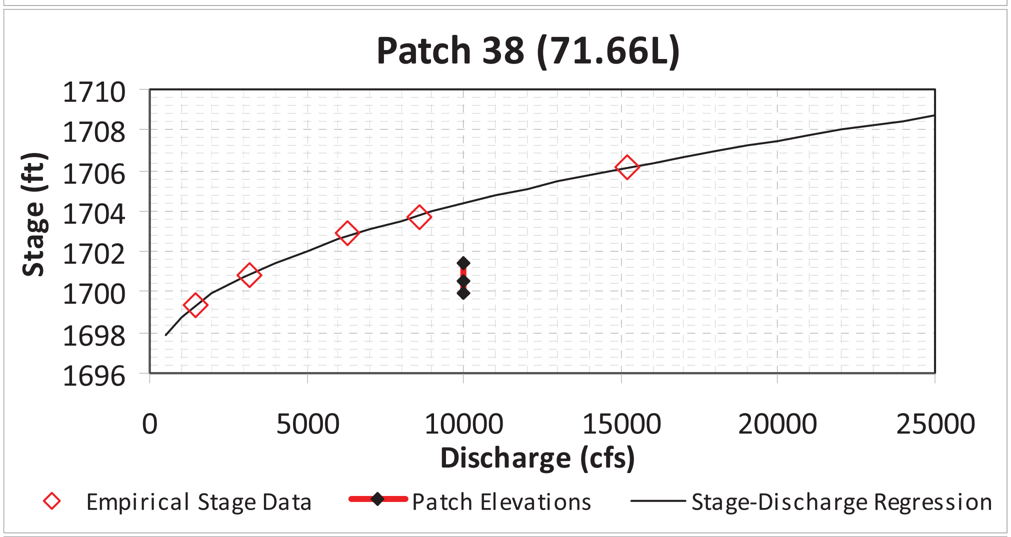
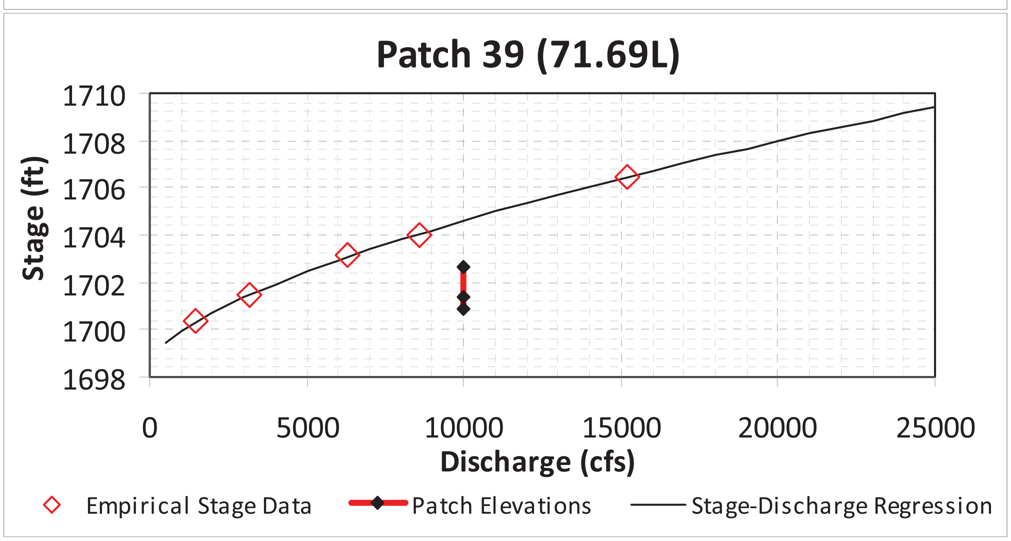


Figure D-13. Spawning Patch Stage Discharge Relationship at Patch 37 (71.52R) (top), Patch 38 (71.66L) (middle), and Patch 39 (71.69L) (bottom).







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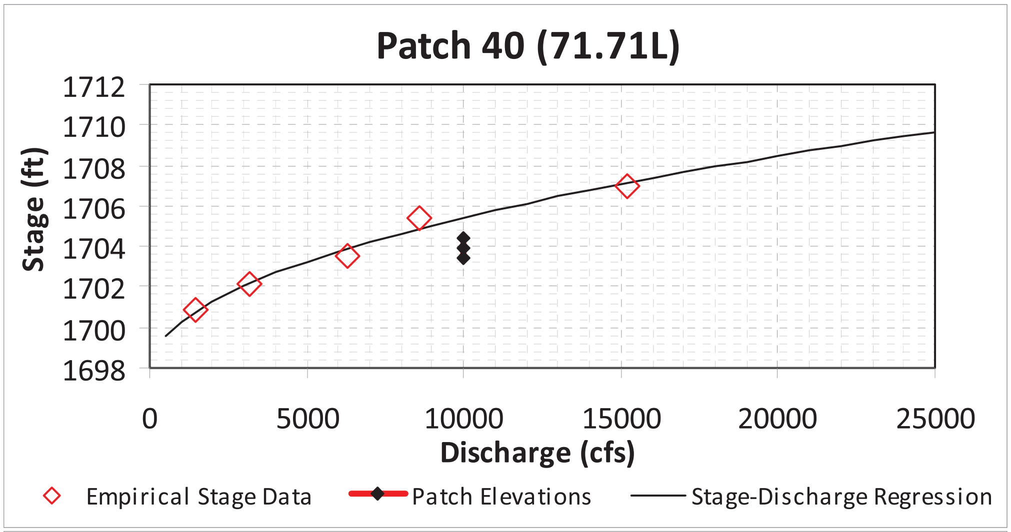

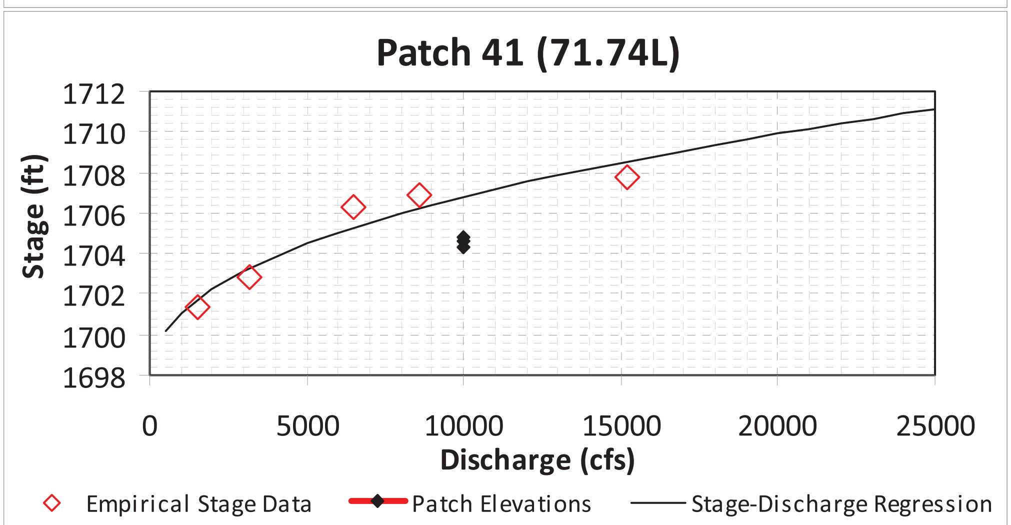

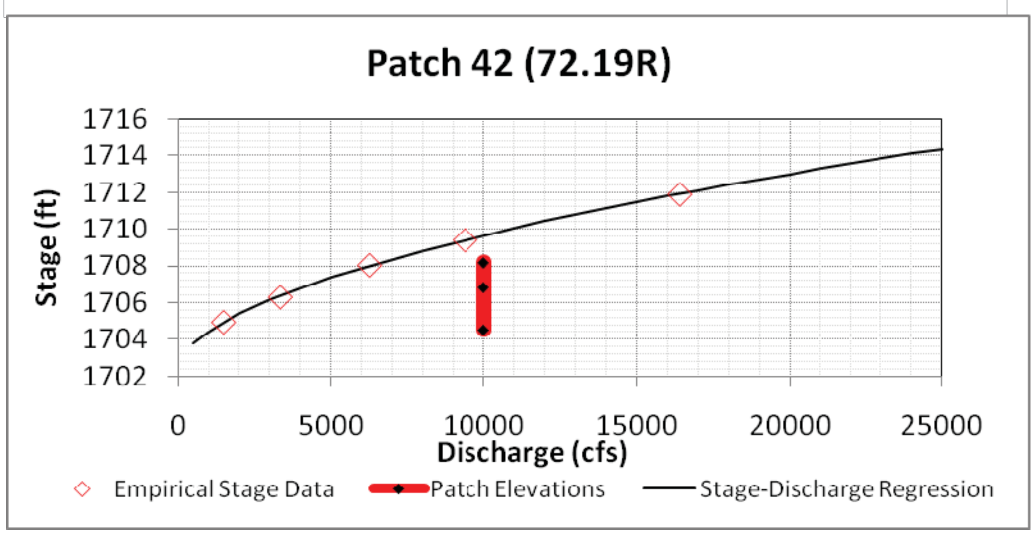

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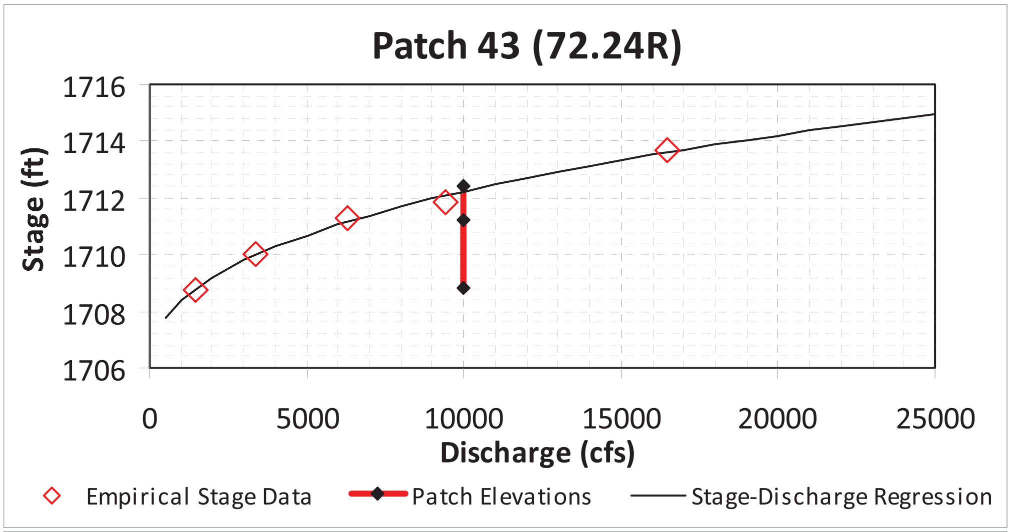

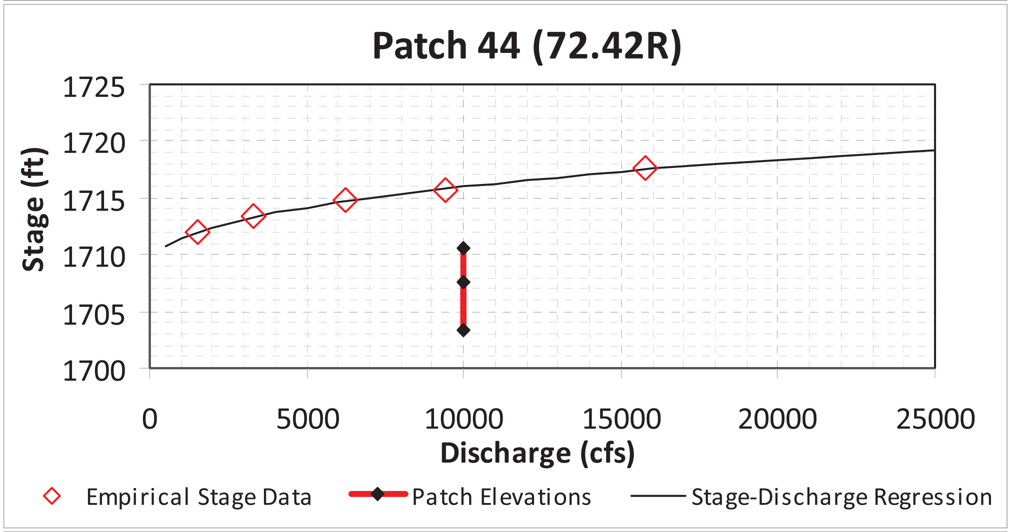

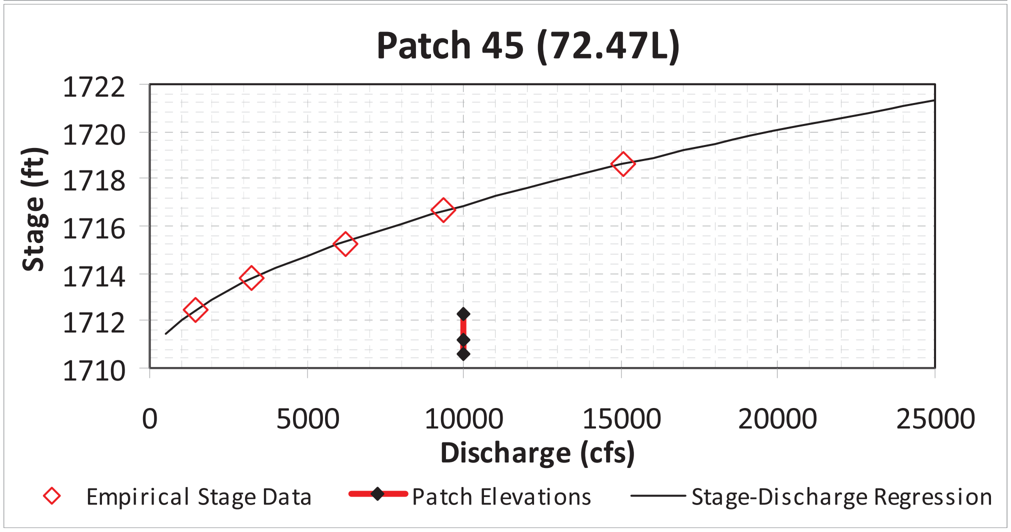

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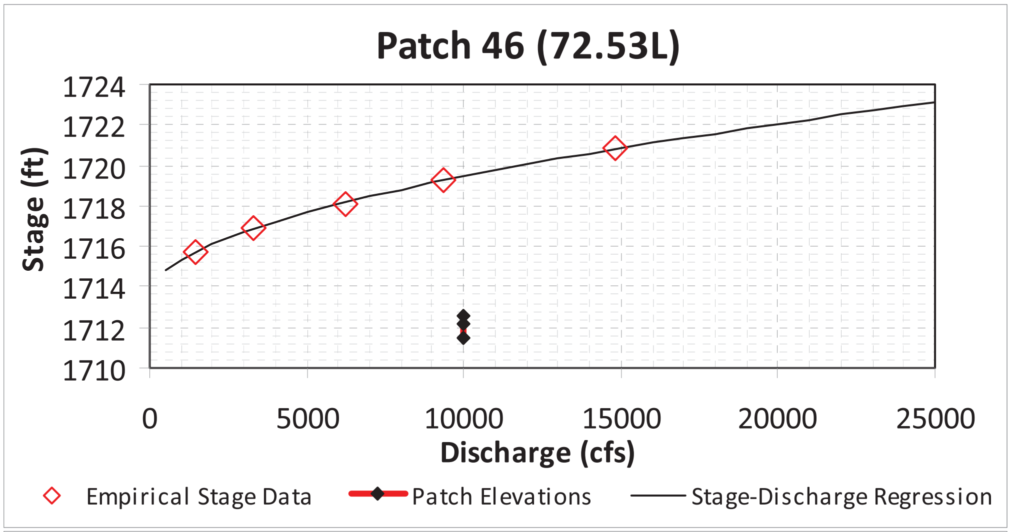

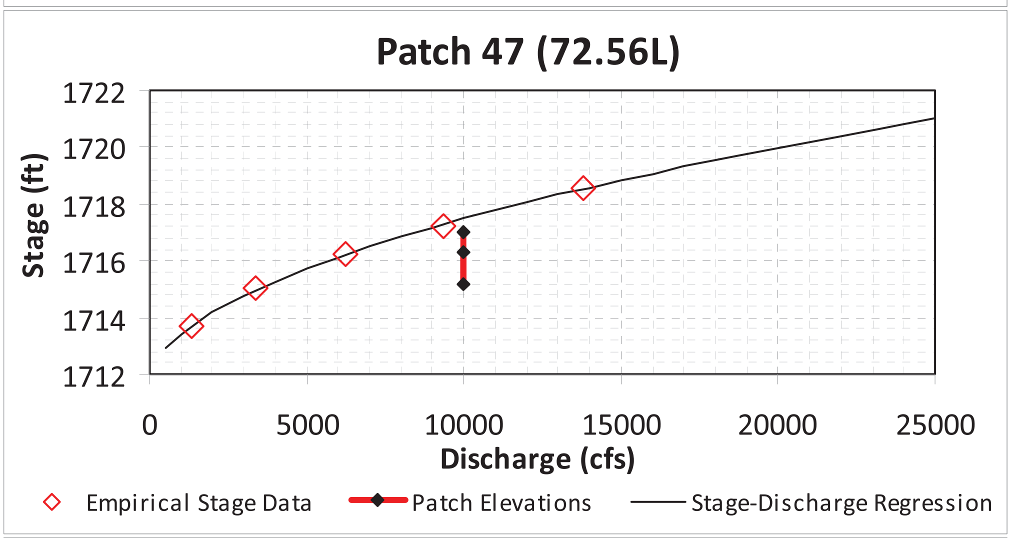

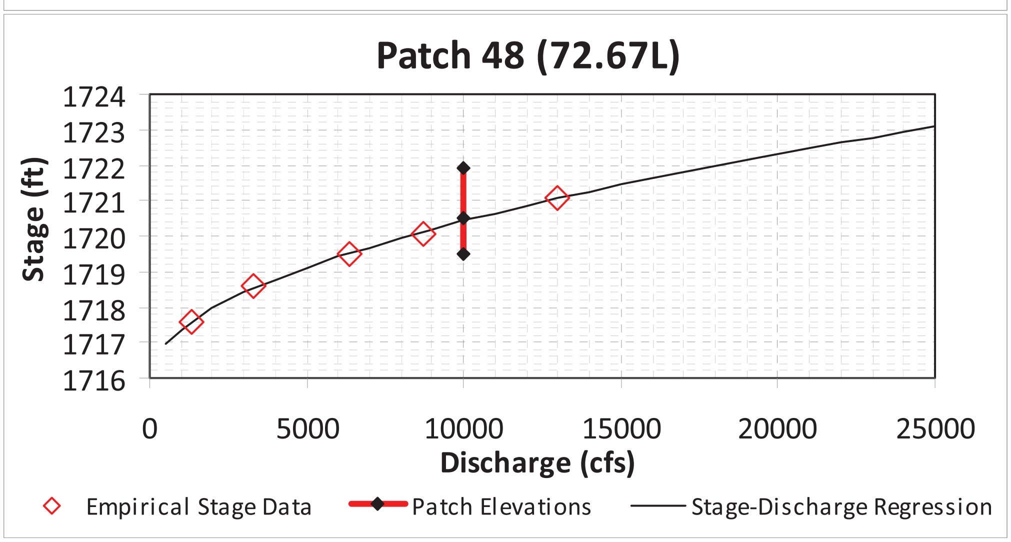

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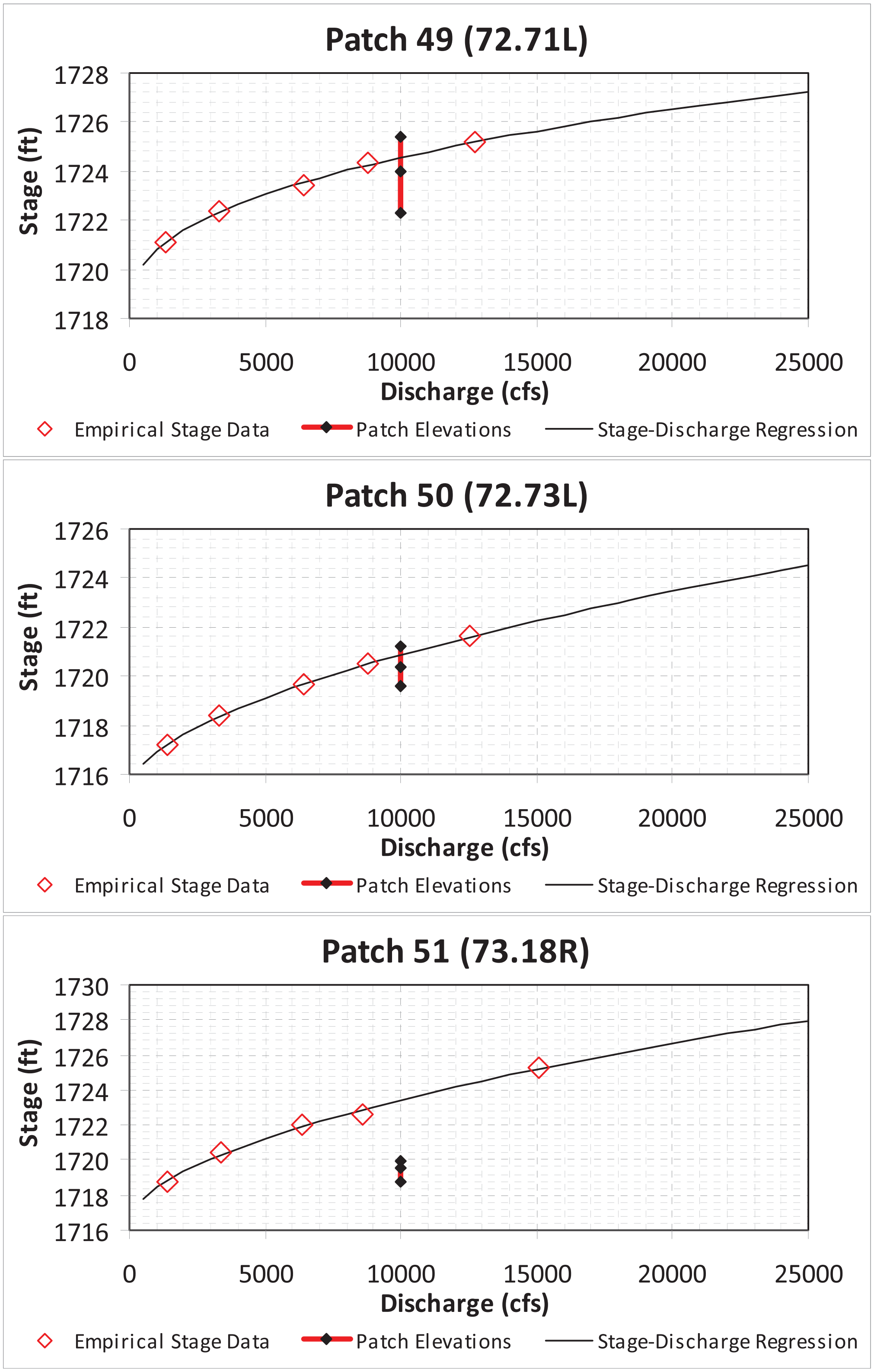

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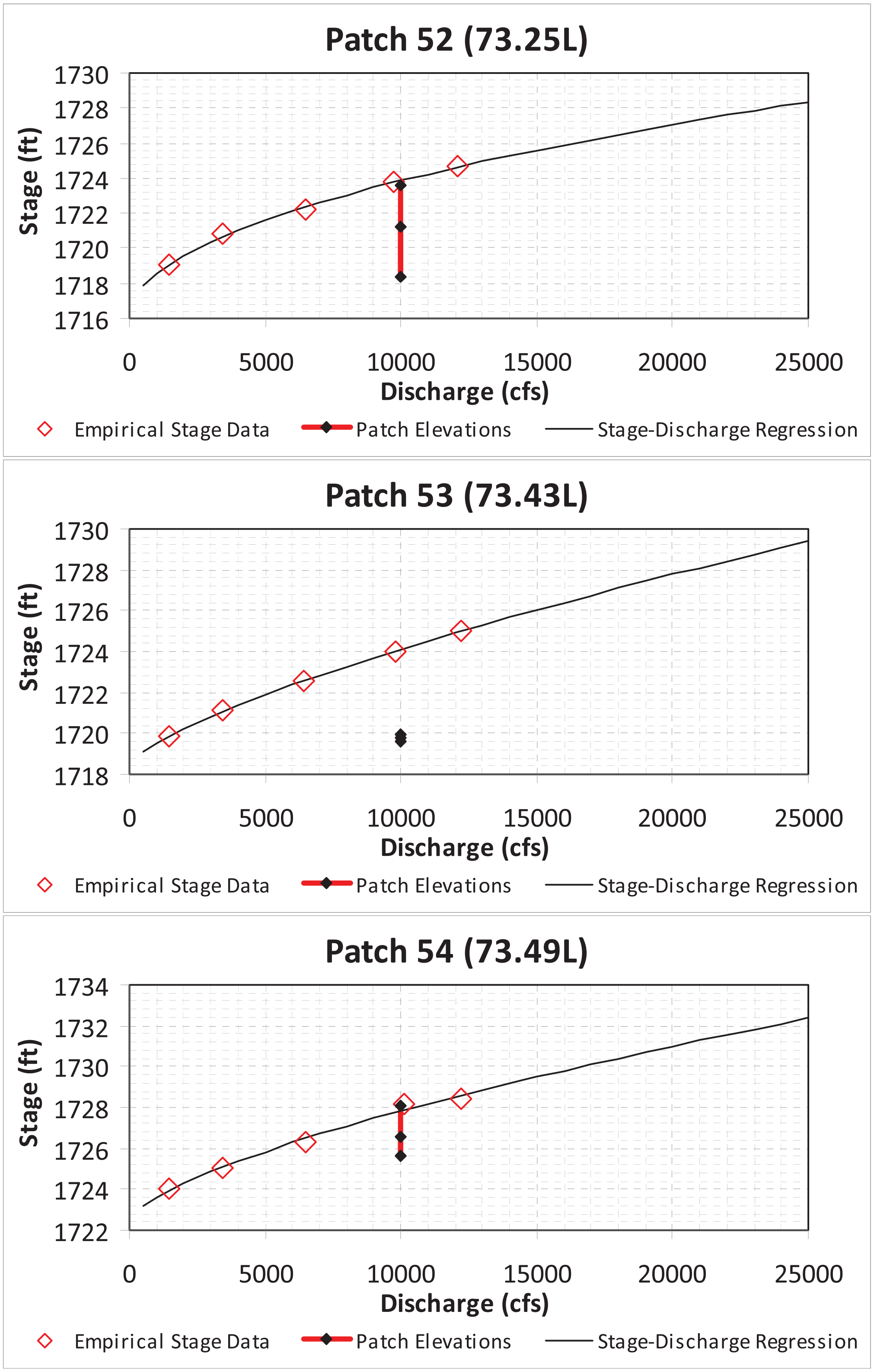

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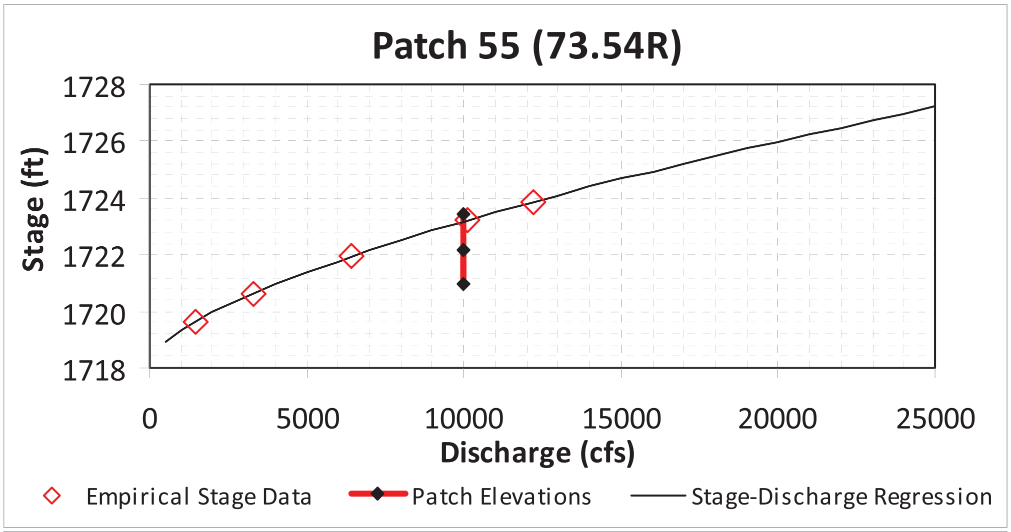
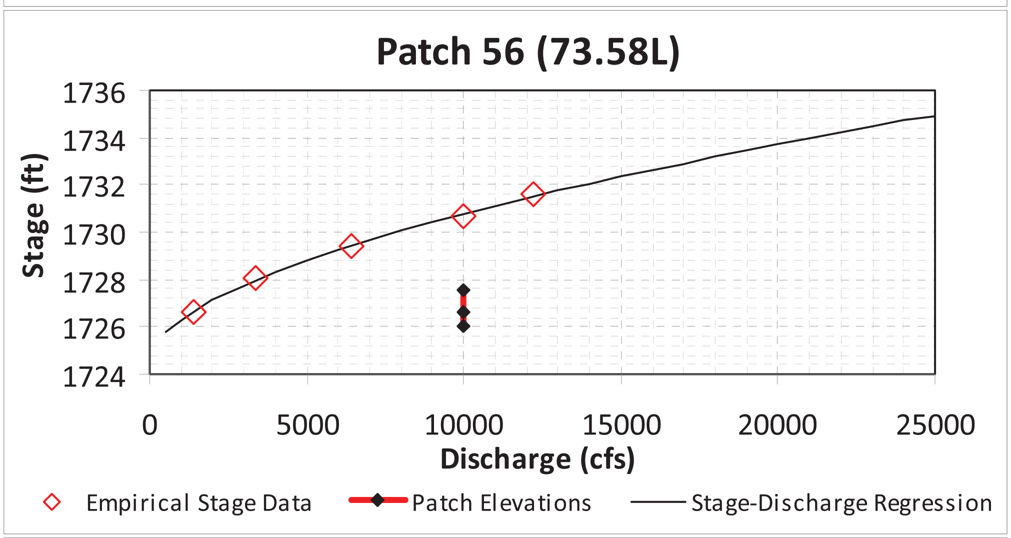




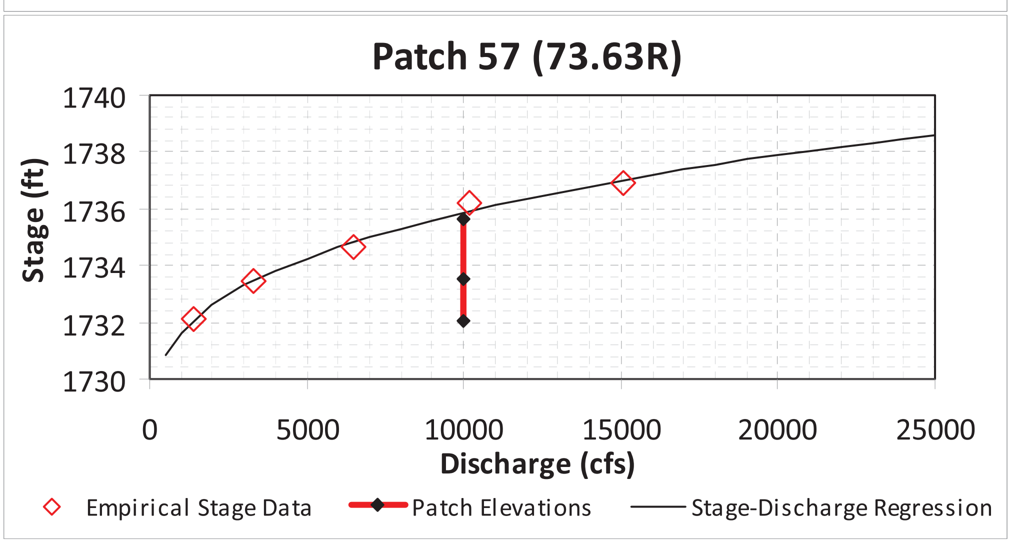
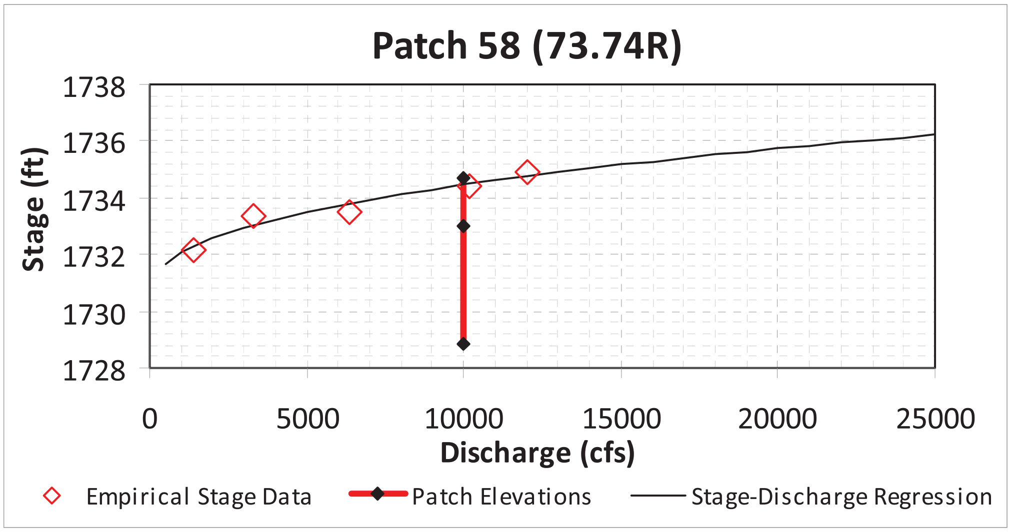


Figure D-20. Spawning Patch Stage Discharge Relationship at Patch 58 (73.74R).



APPENDIX E

Empirical Depth and Velocity Mapping

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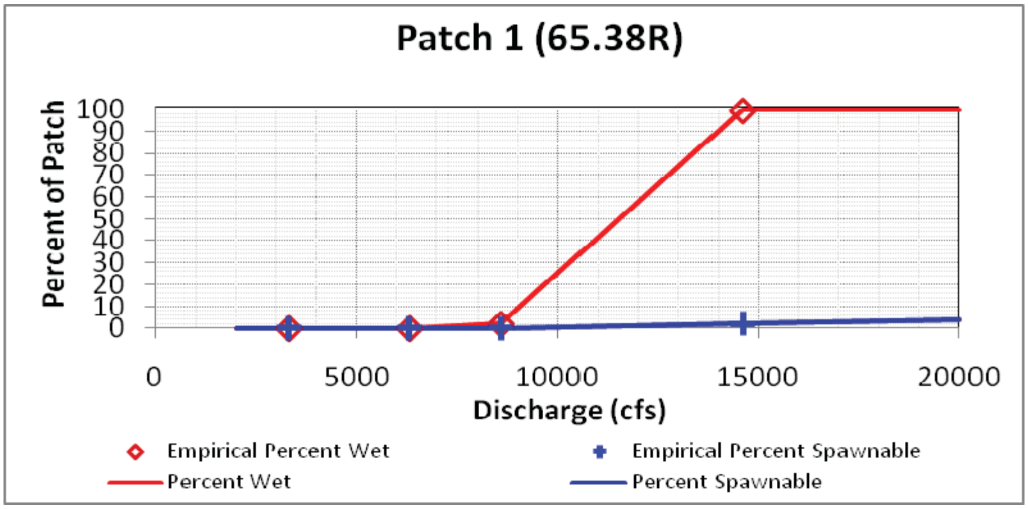
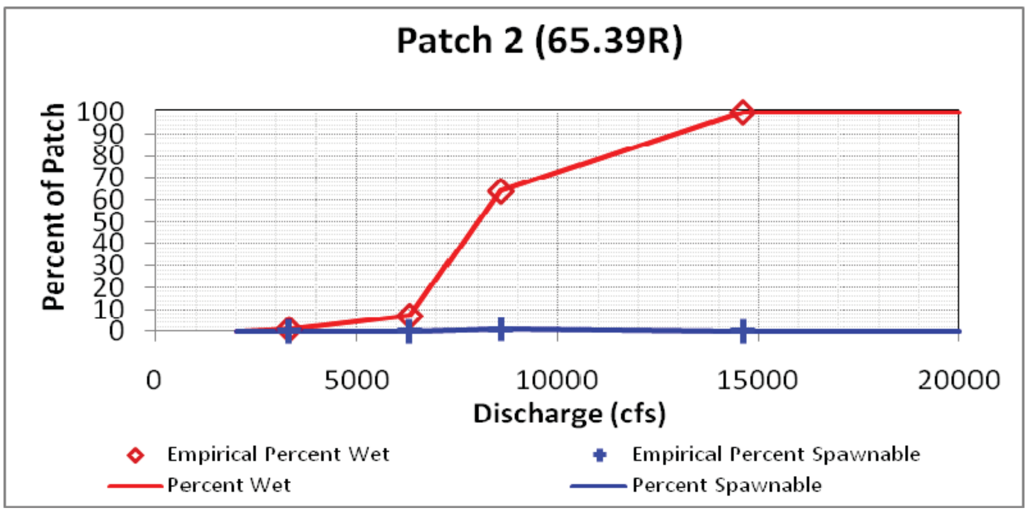




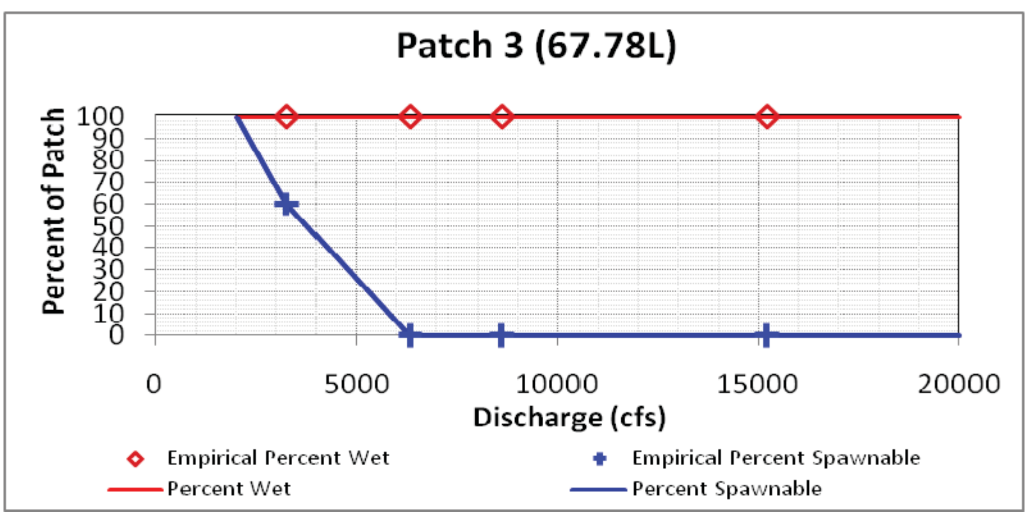
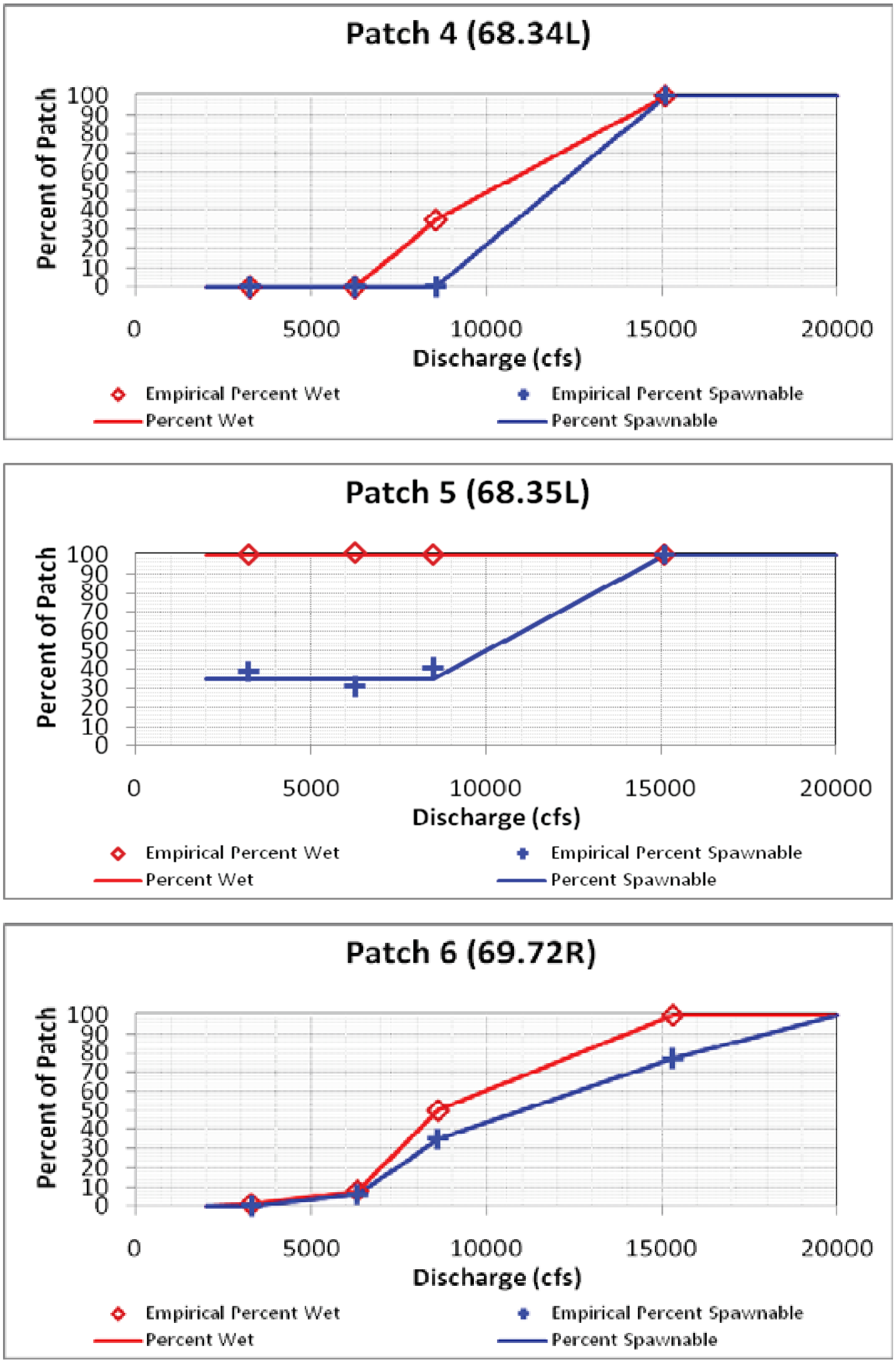


Figure E-2. Empirical Mapping Data and Piece-wise Linear Relationships of the Percent Spawnable and Percent Wet at Patch 4 (68.34L) (top), Patch 5 (68.35L) (middle), and Patch 6 (69.72R) (bottom).



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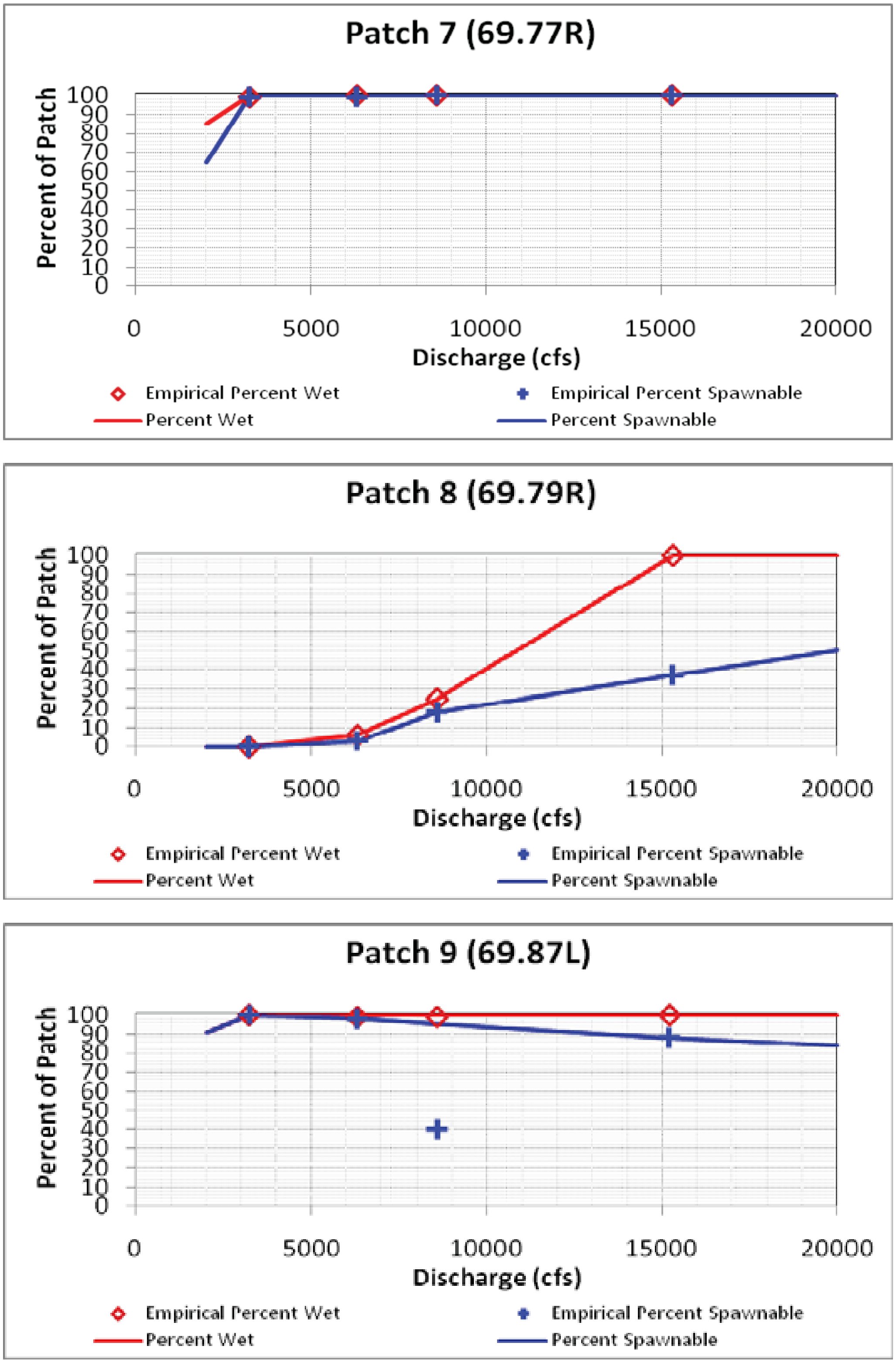

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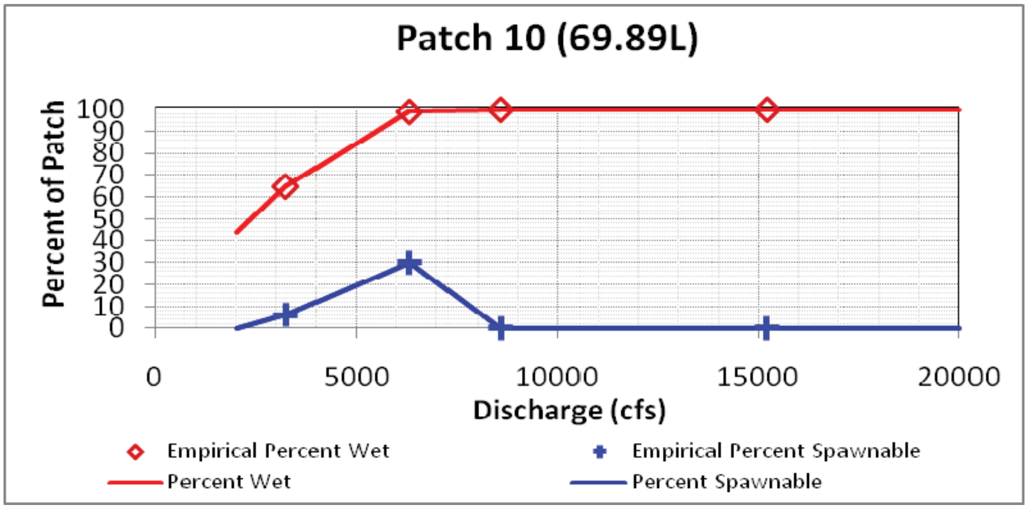

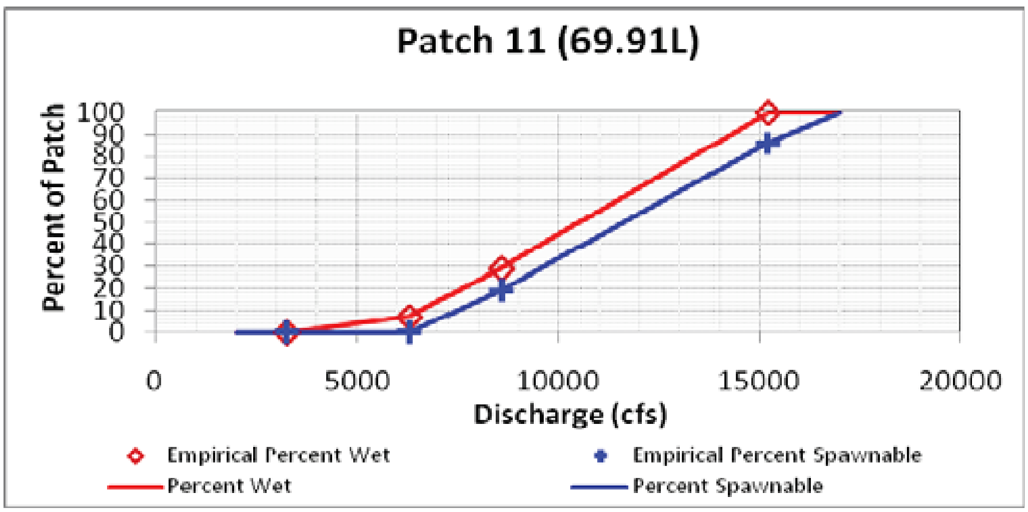

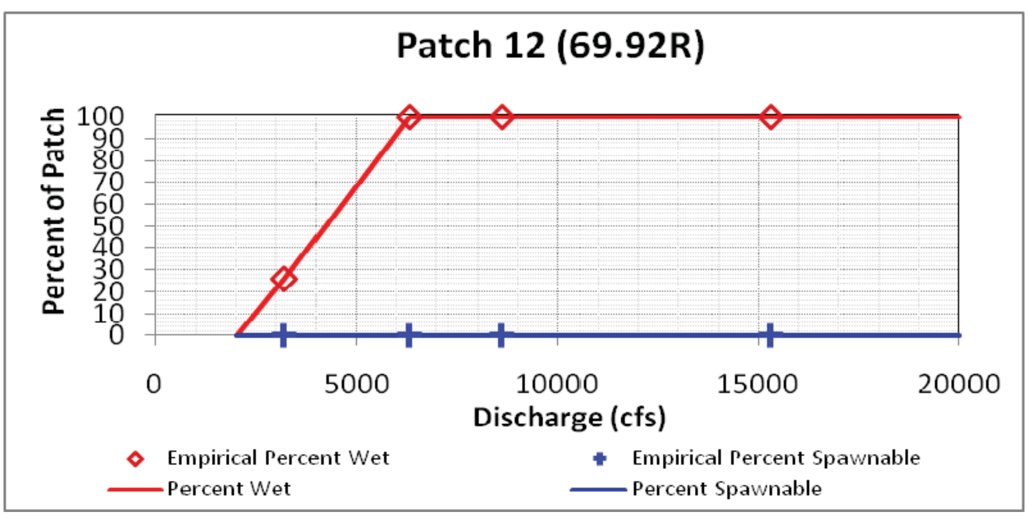

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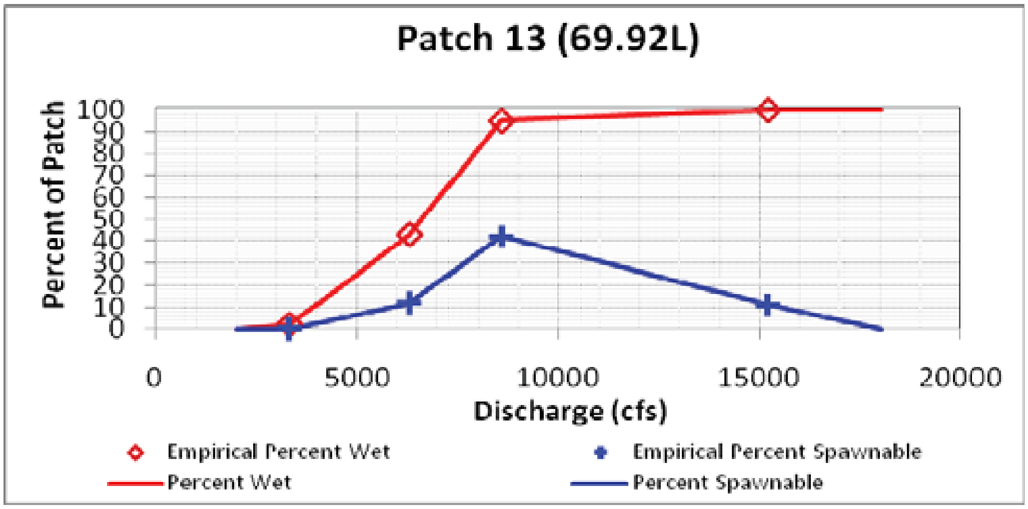

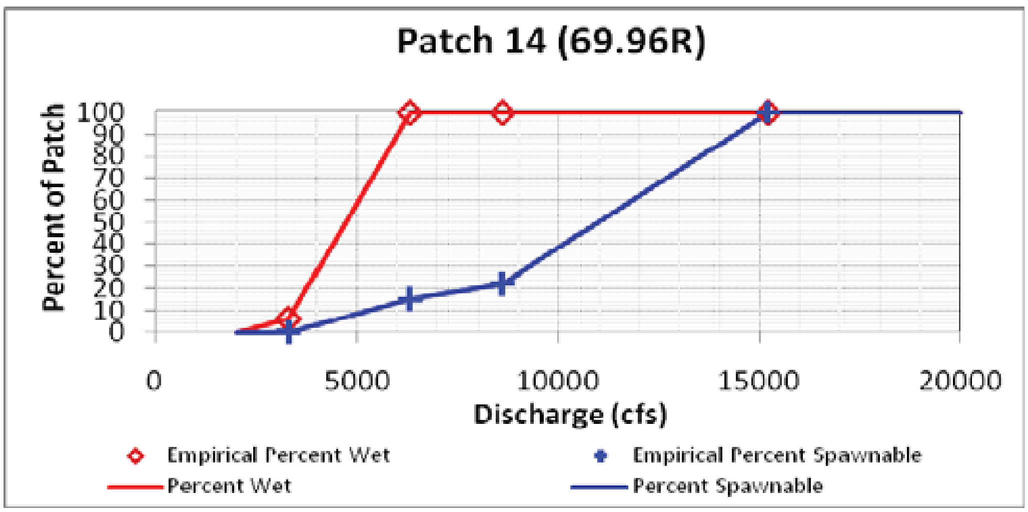

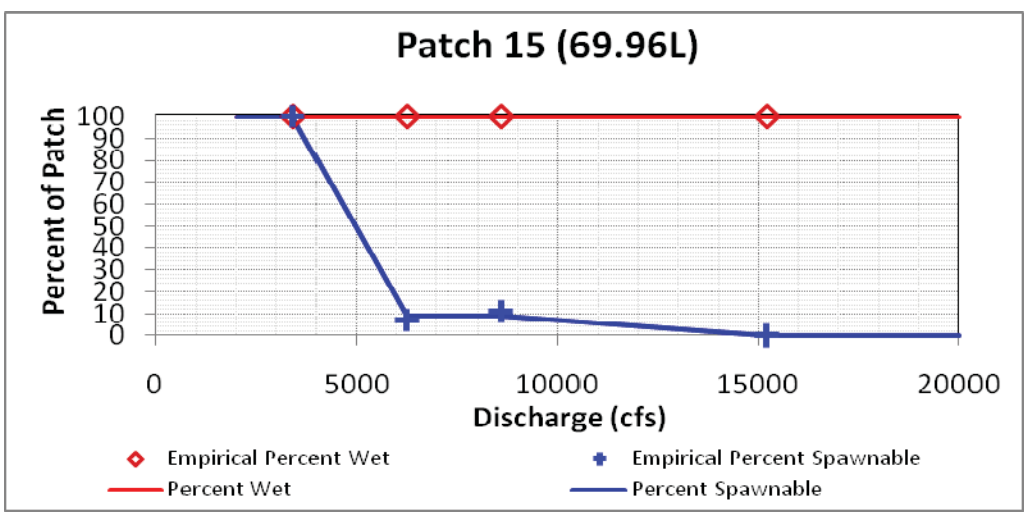

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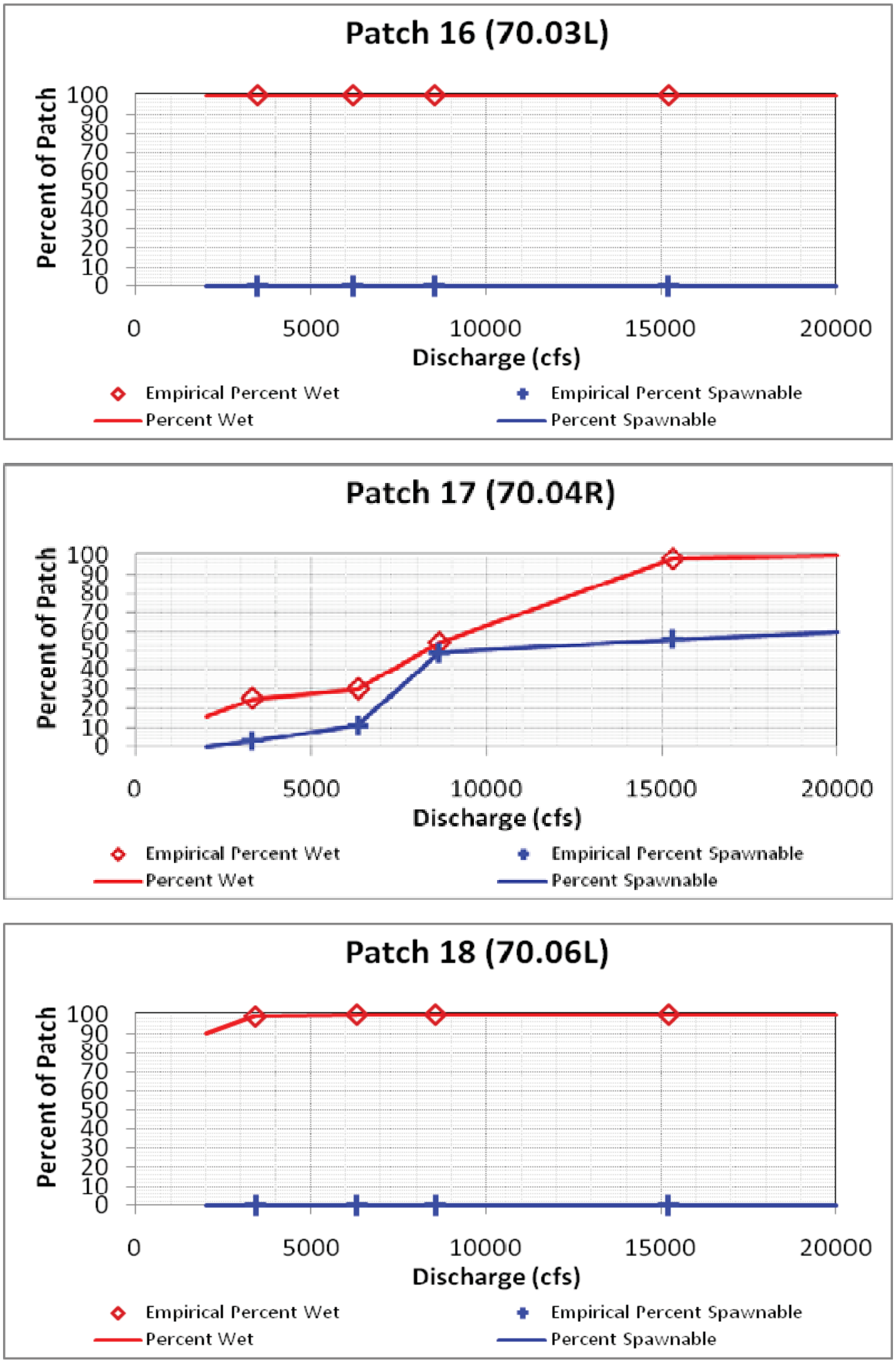

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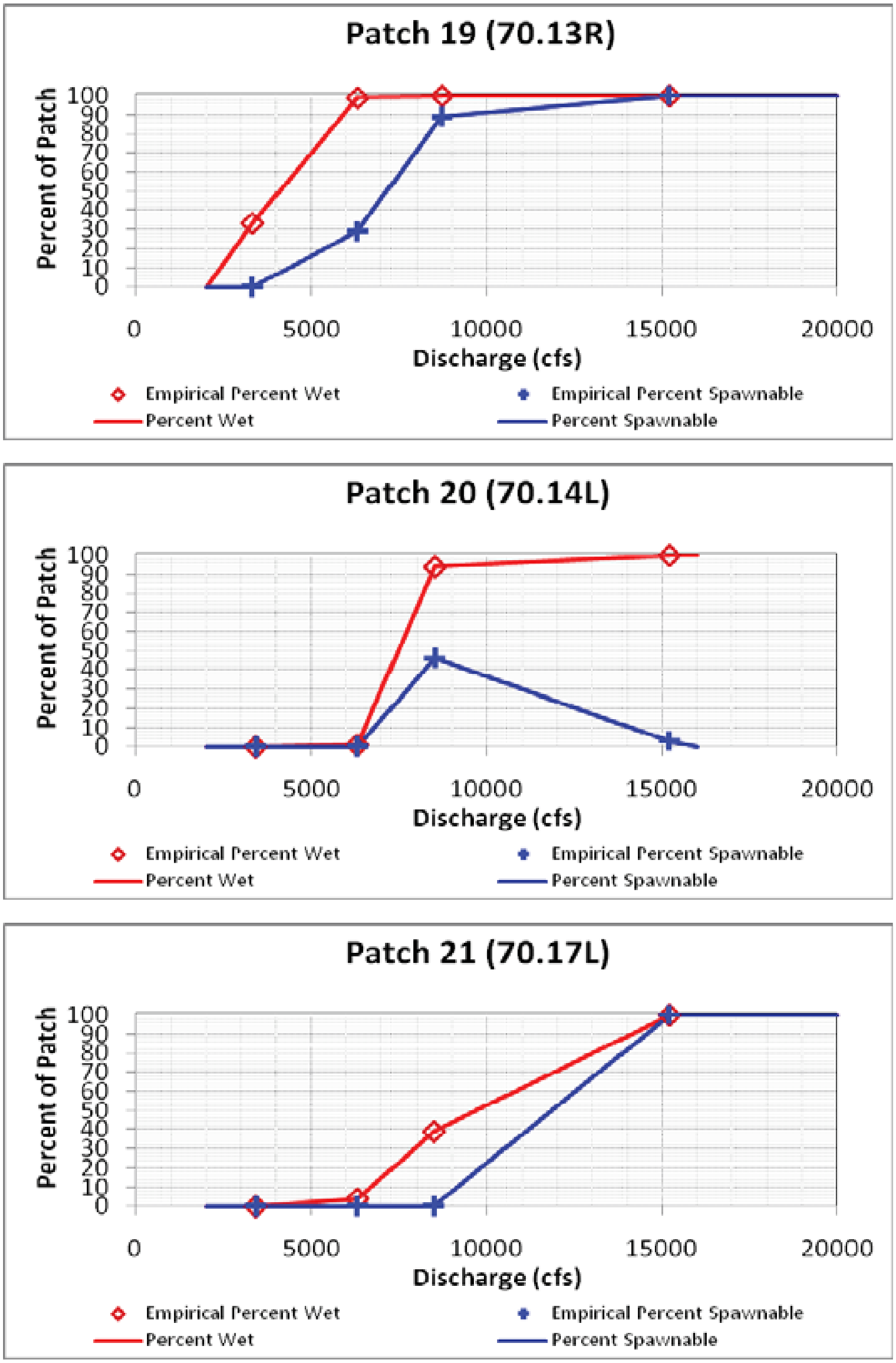

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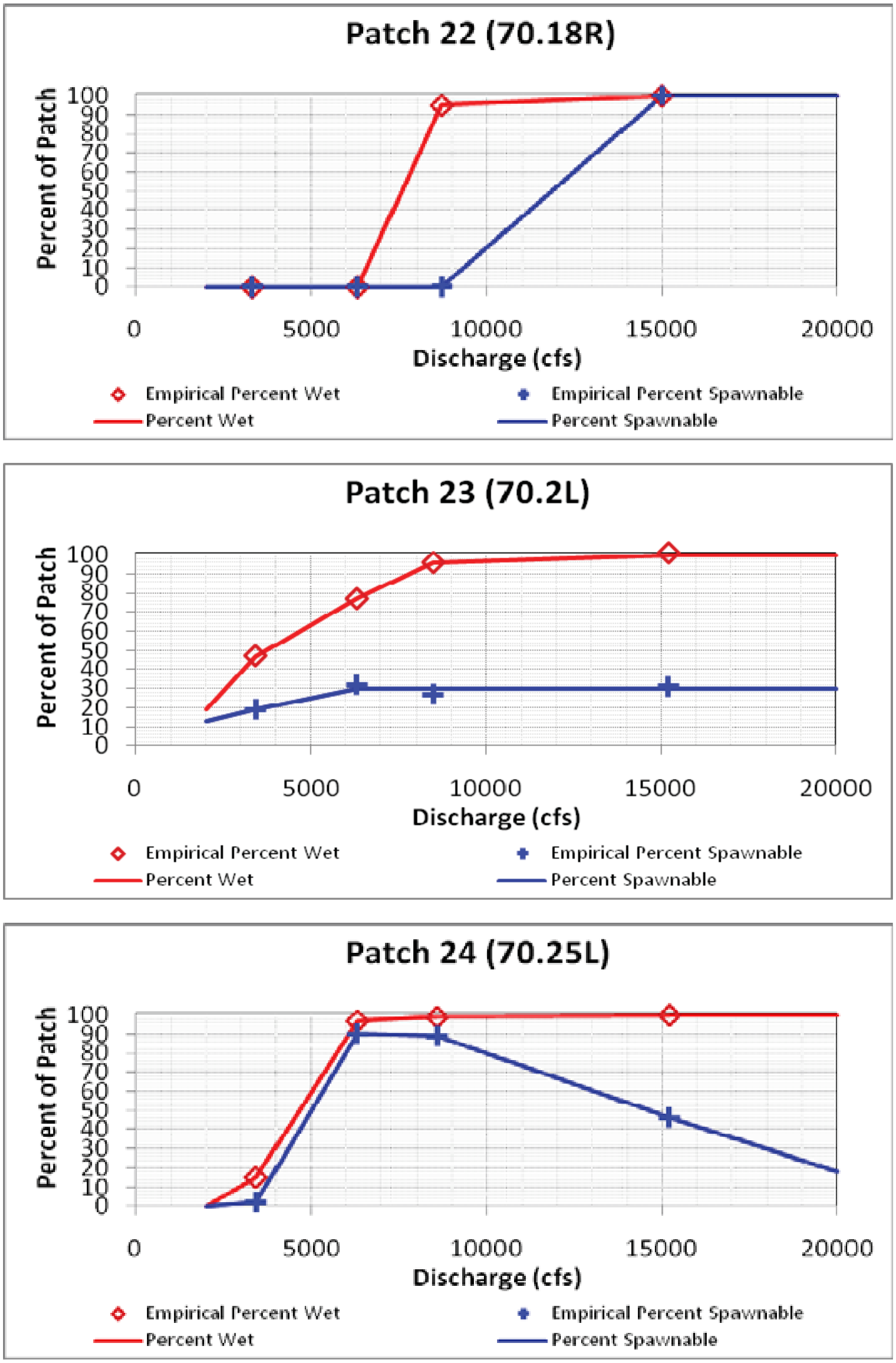

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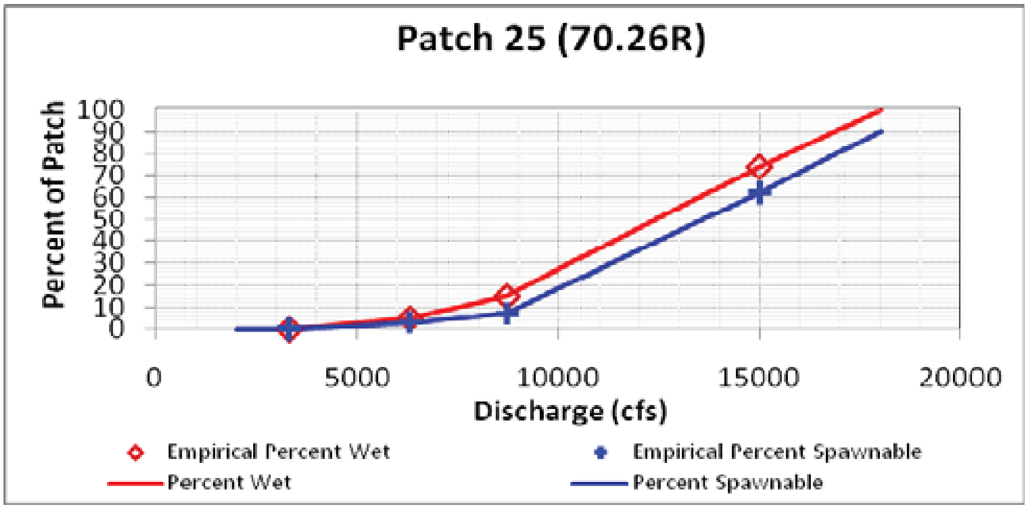

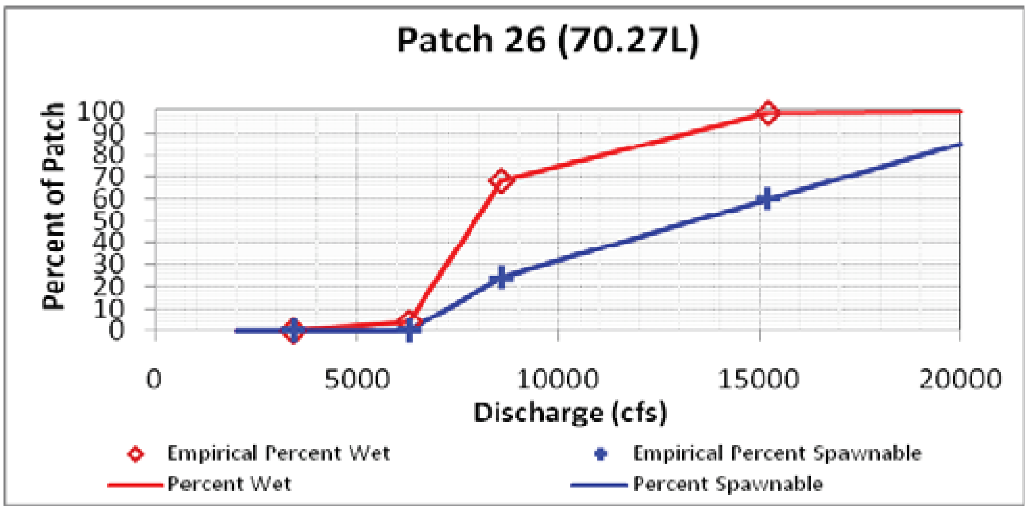

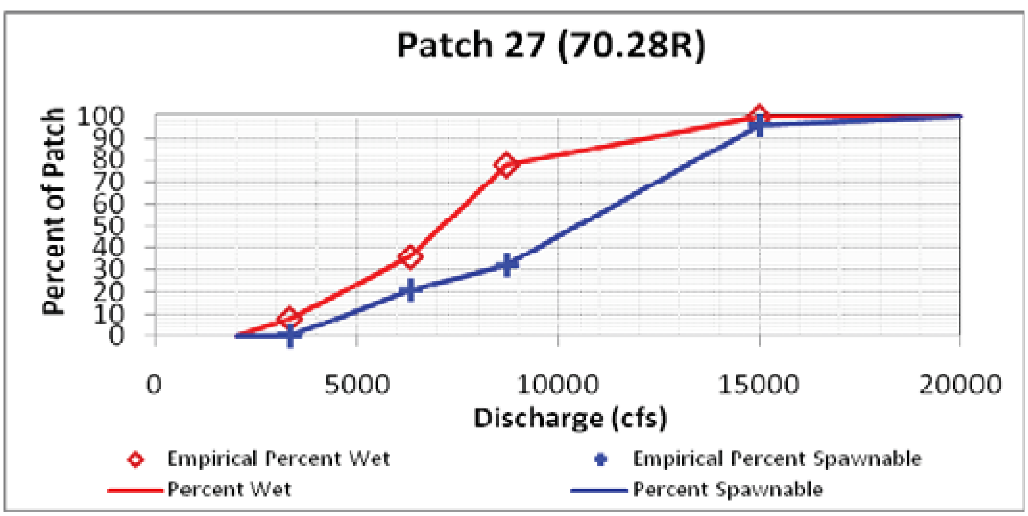

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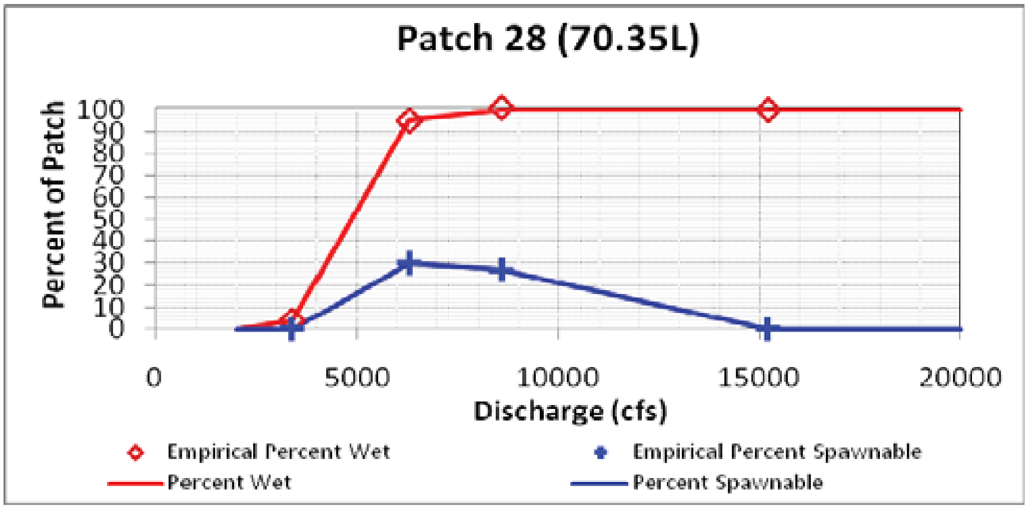

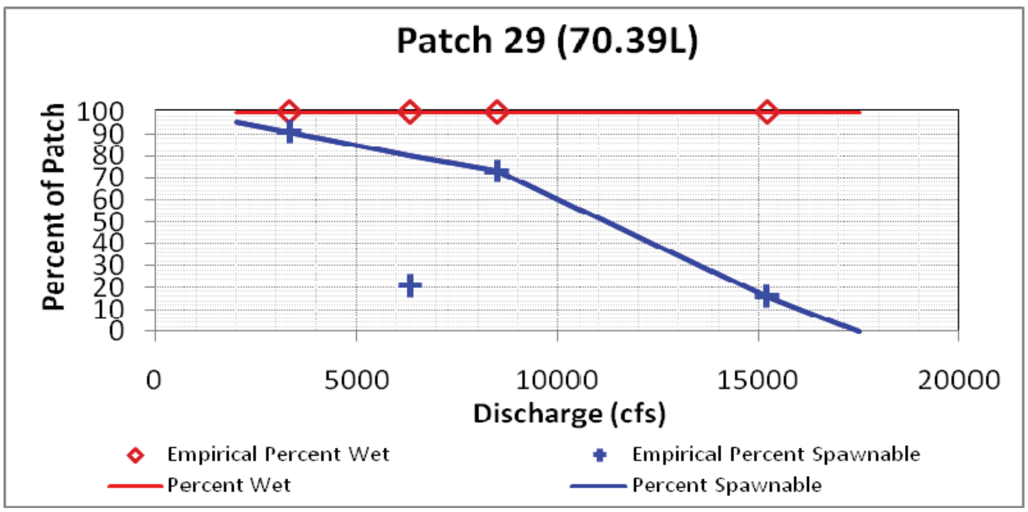

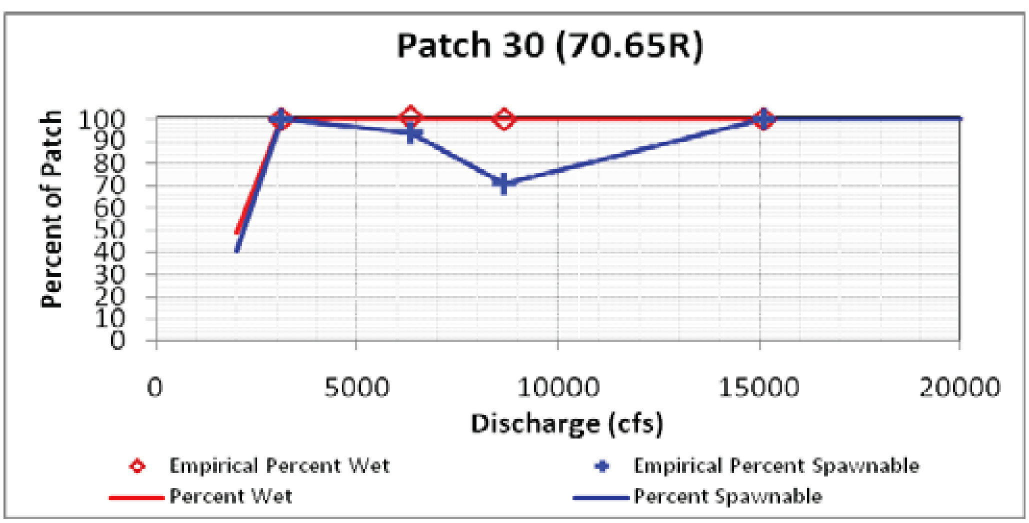

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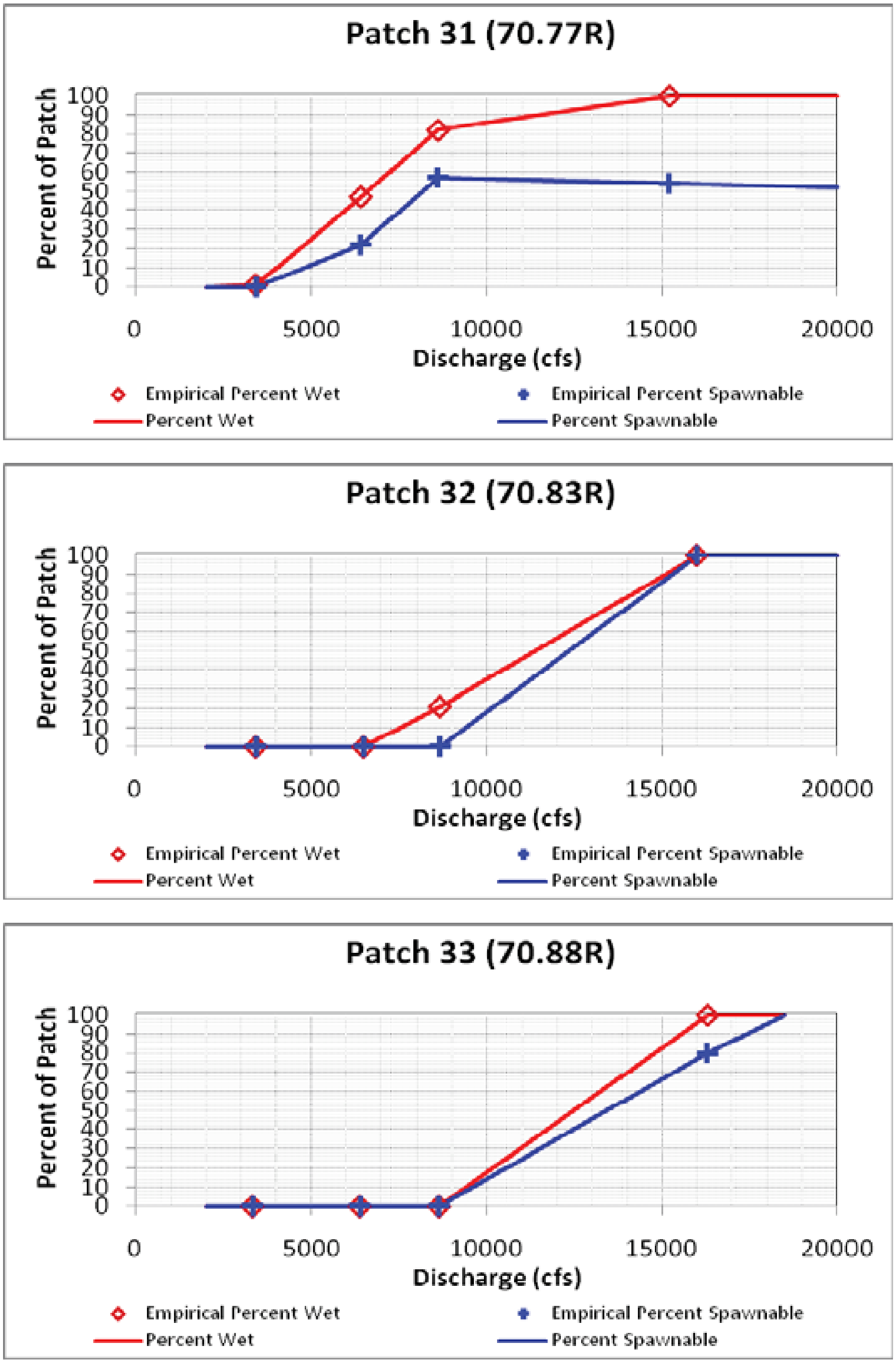

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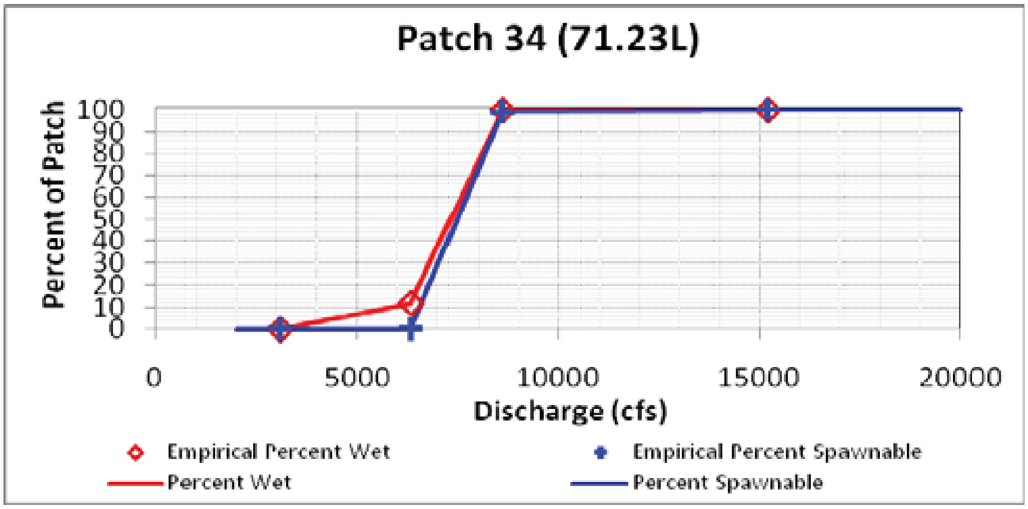

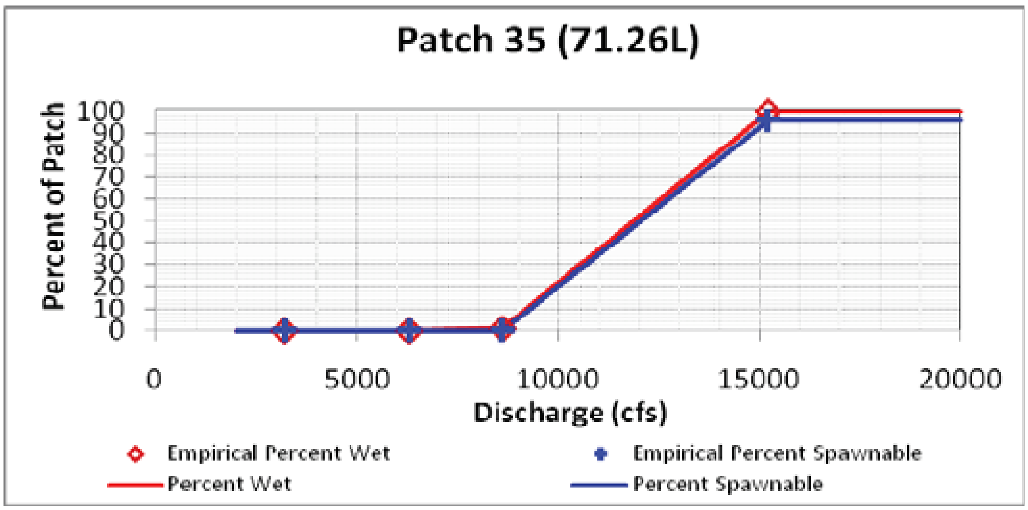

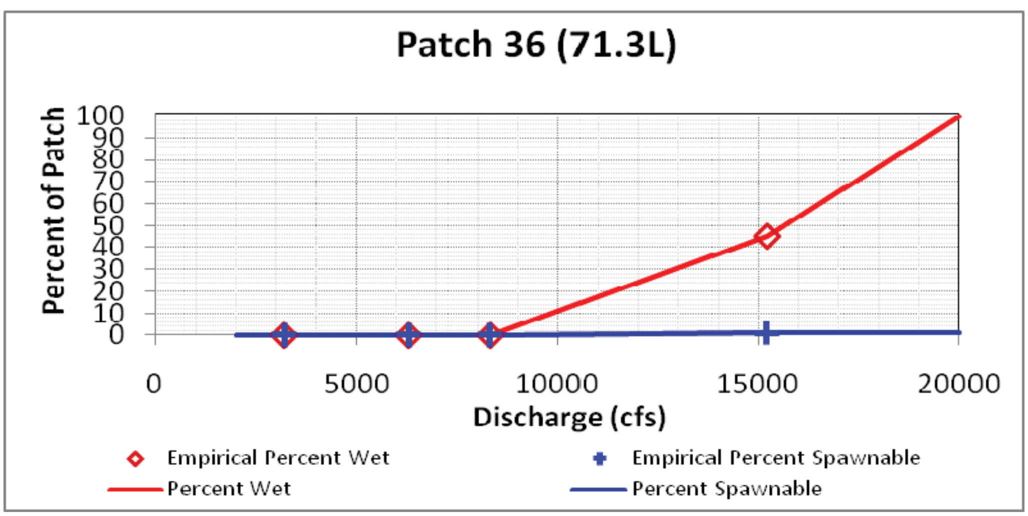

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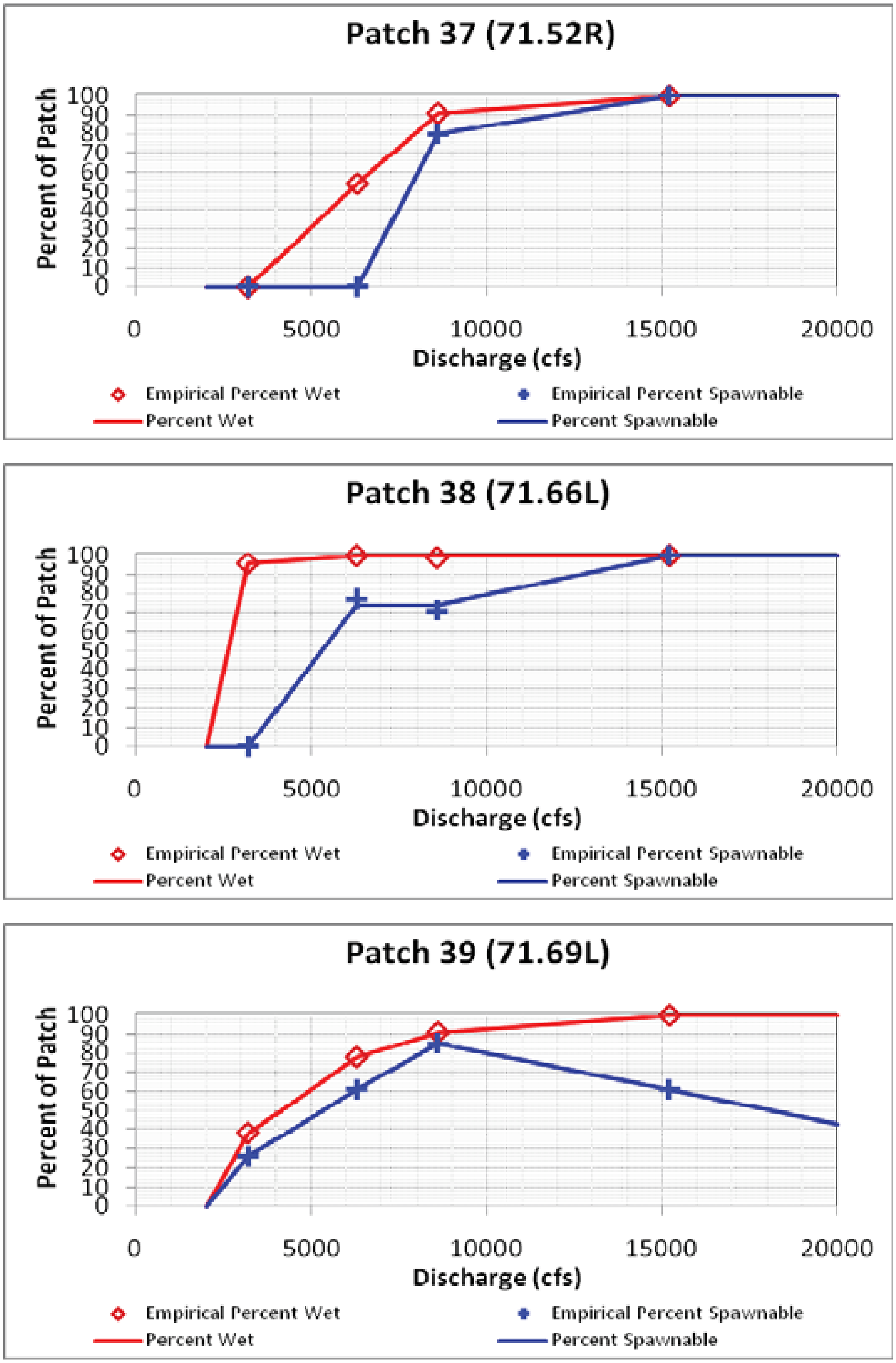

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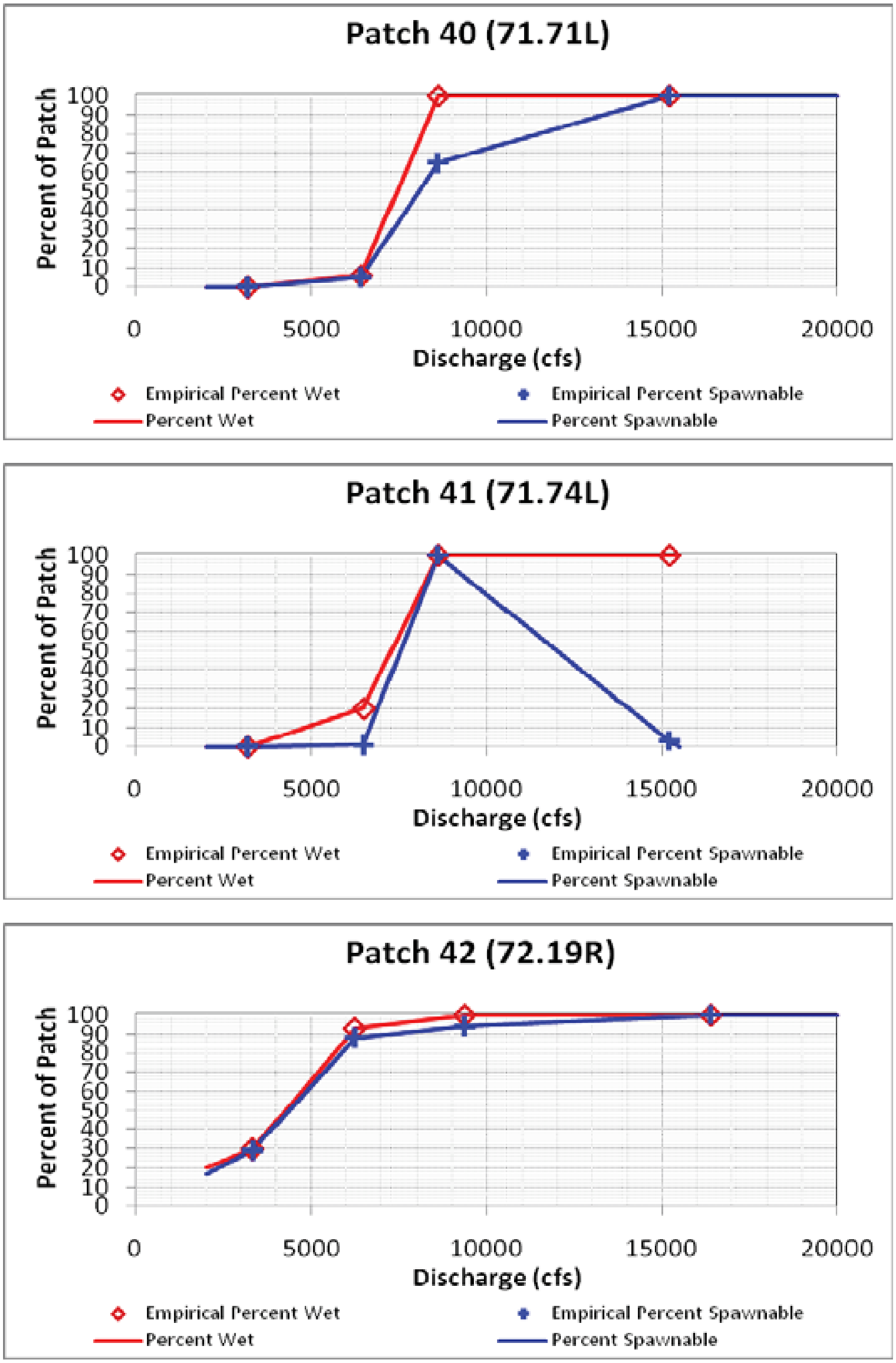
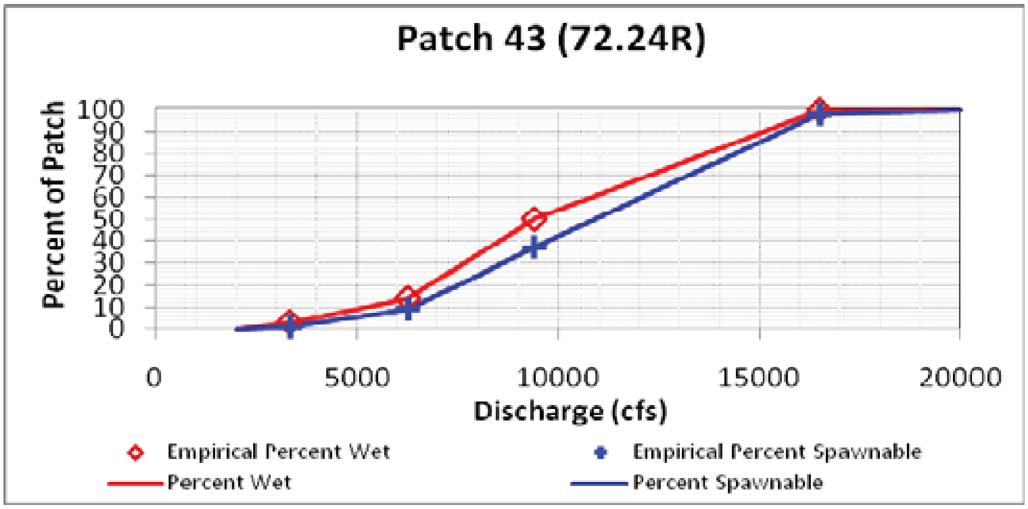
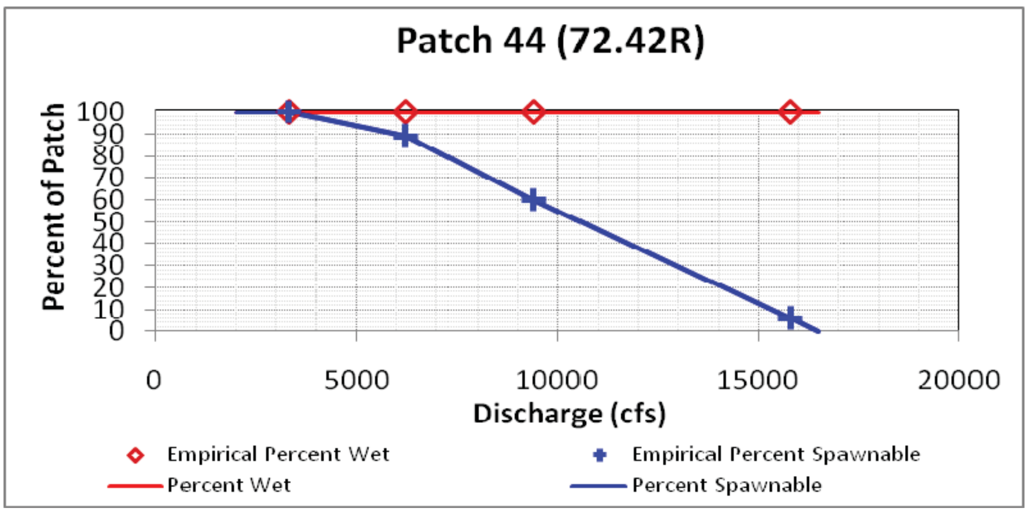


Figure E-15. Empirical Mapping Data and Piece-wise Linear Relationships of the Percent Spawnable and Percent Wet at Patch 43 (72.24R) (top), Patch 44 (72.42R) (middle), and Patch 45 (72.47L) (bottom).





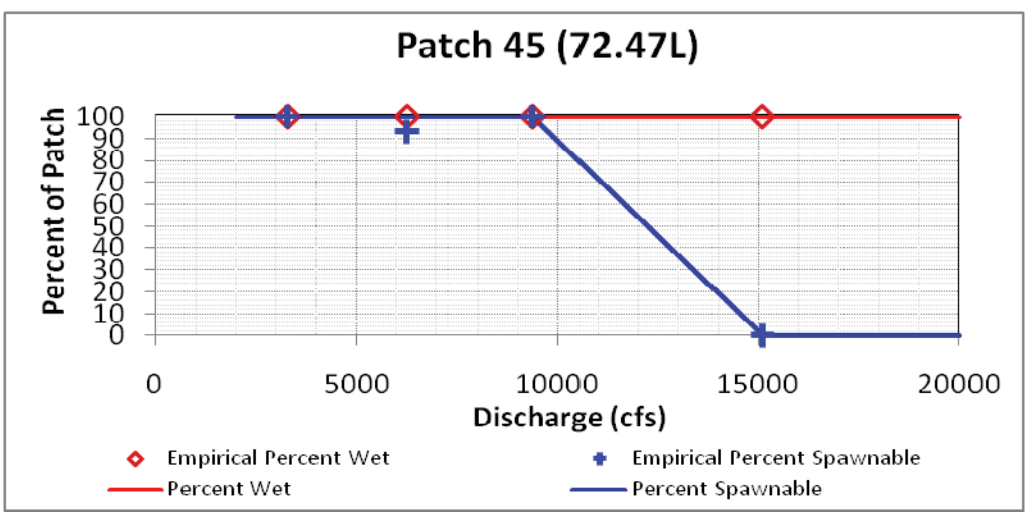


Figure E-16. Empirical Mapping Data and Piece-wise Linear Relationships of the Percent Spawnable and Percent Wet at Patch 46 (72.53L) (top), Patch 47 (72.56L) (middle), and Patch 48 (72.67L) (bottom).

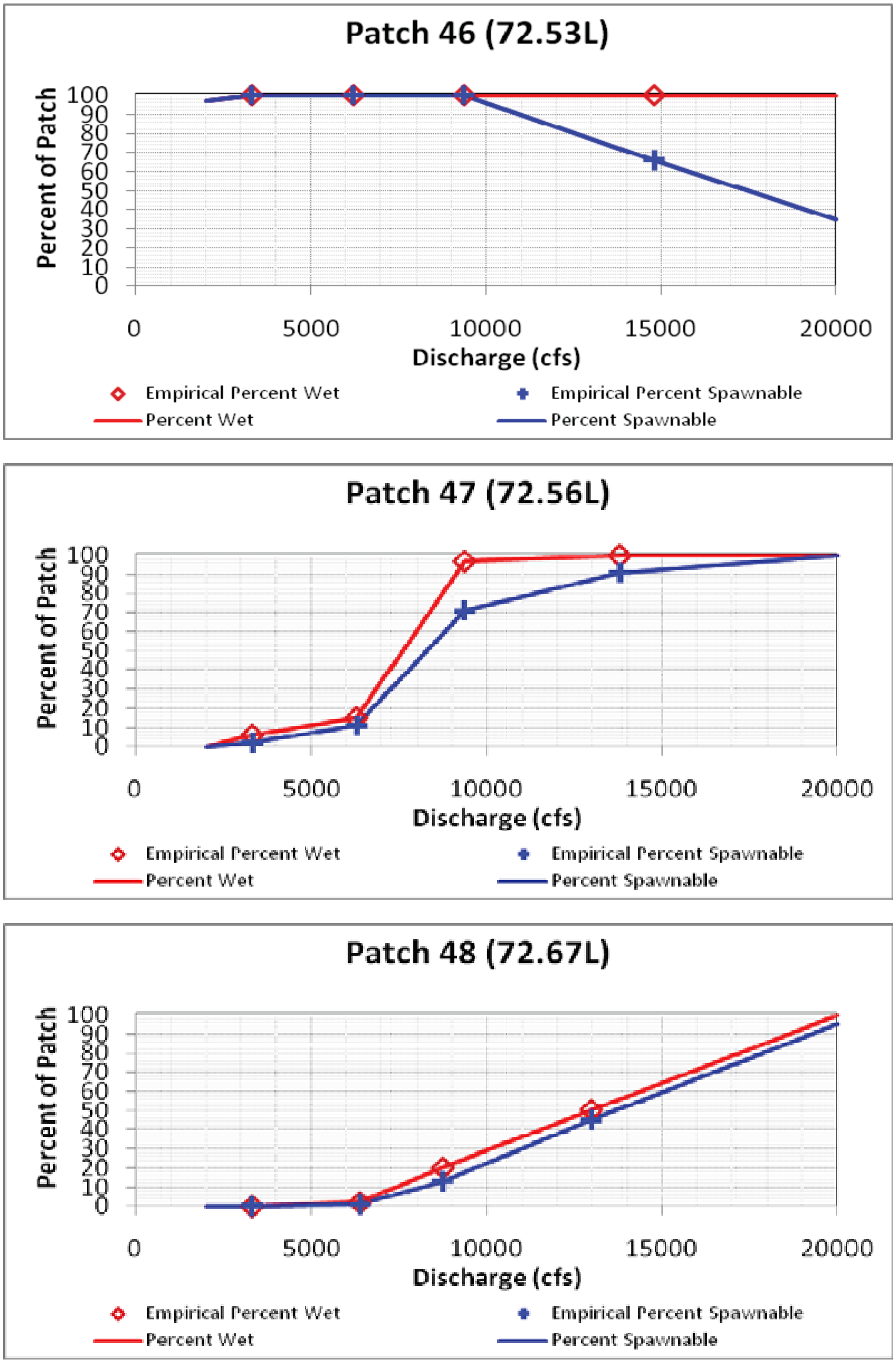


Figure E-17. Empirical Mapping Data and Piece-wise Linear Relationships of the Percent Spawnable and Percent Wet at Patch 49 (72.71L) (top), Patch 50 (72.73L) (middle), and Patch 51 (73.18R) (bottom).

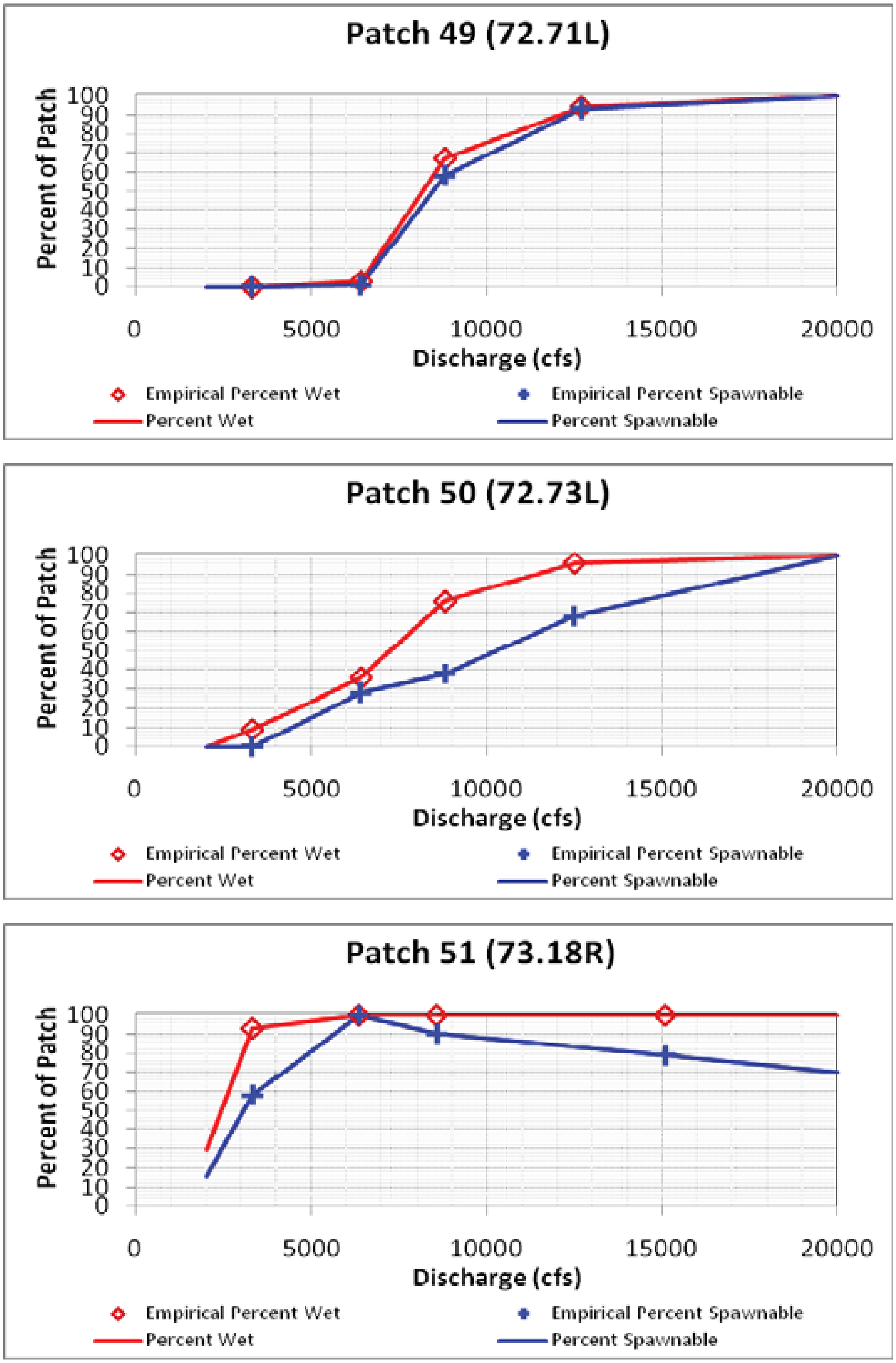
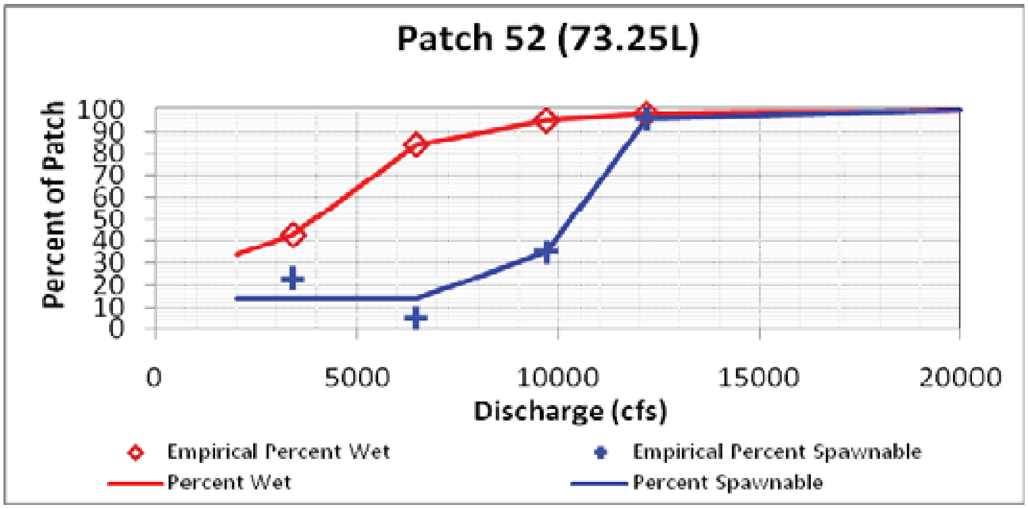
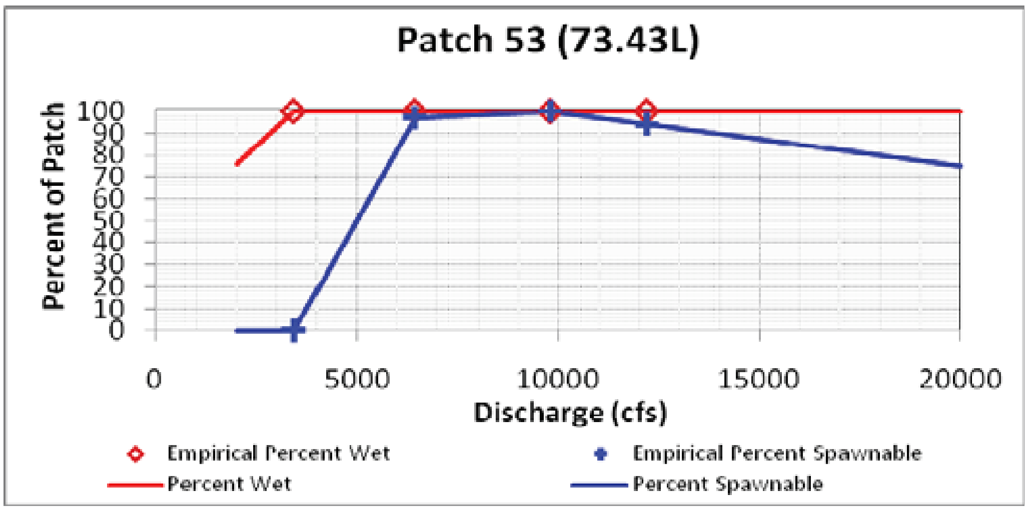


Figure E-18. Empirical Mapping Data and Piece-wise Linear Relationships of the Percent Spawnable and Percent Wet at Patch 52 (73.25L) (top), Patch 53 (73.43L) (middle), and Patch 54 (73.49L) (bottom).





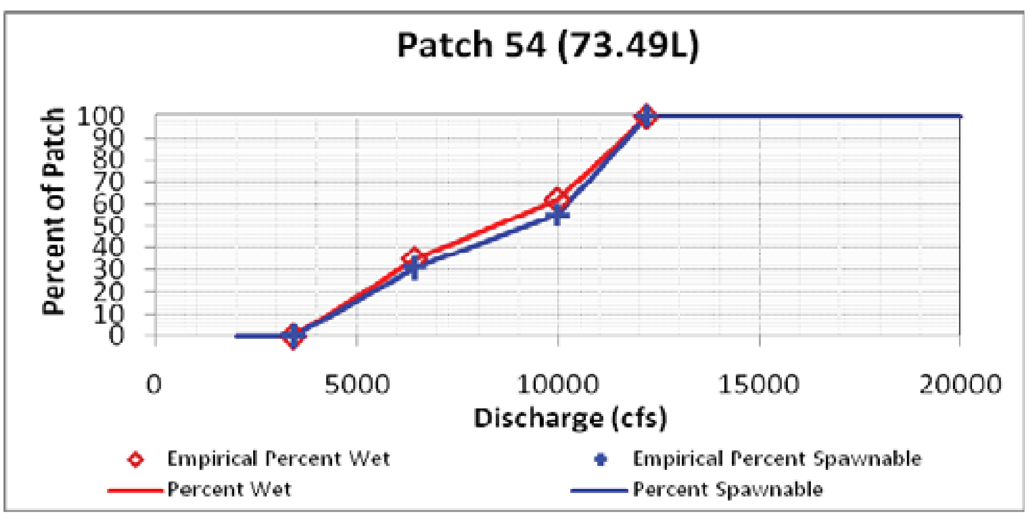
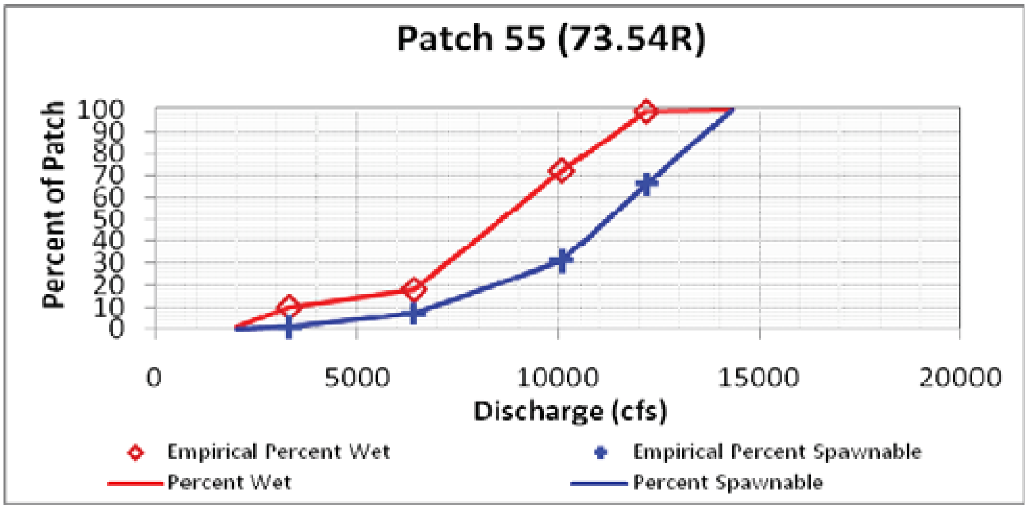
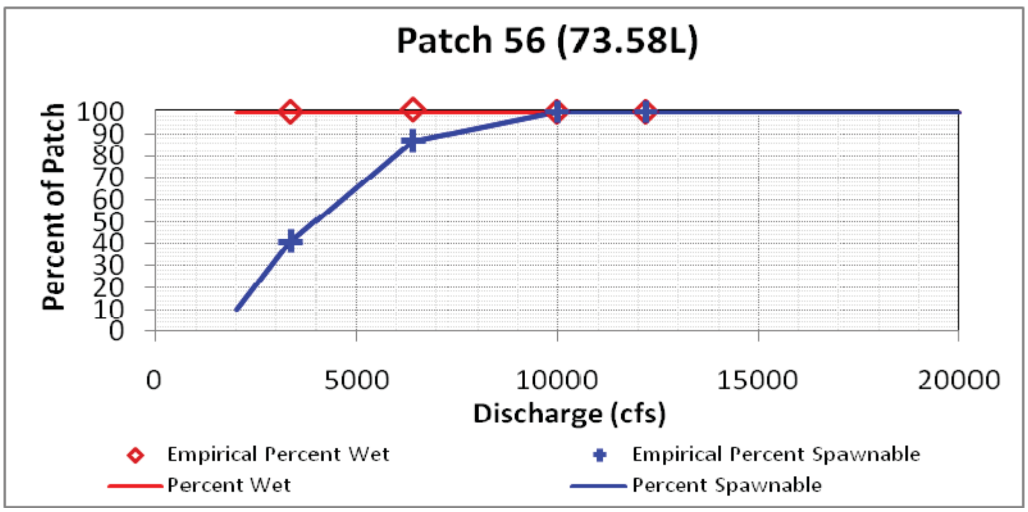


Figure E-19. Empirical Mapping Data and Piece-wise Linear Relationships of the Percent Spawnable and Percent Wet at Patch 55 (73.54R) (top), Patch 56 (73.58R) (middle), and Patch 57 (73.63R) (bottom).





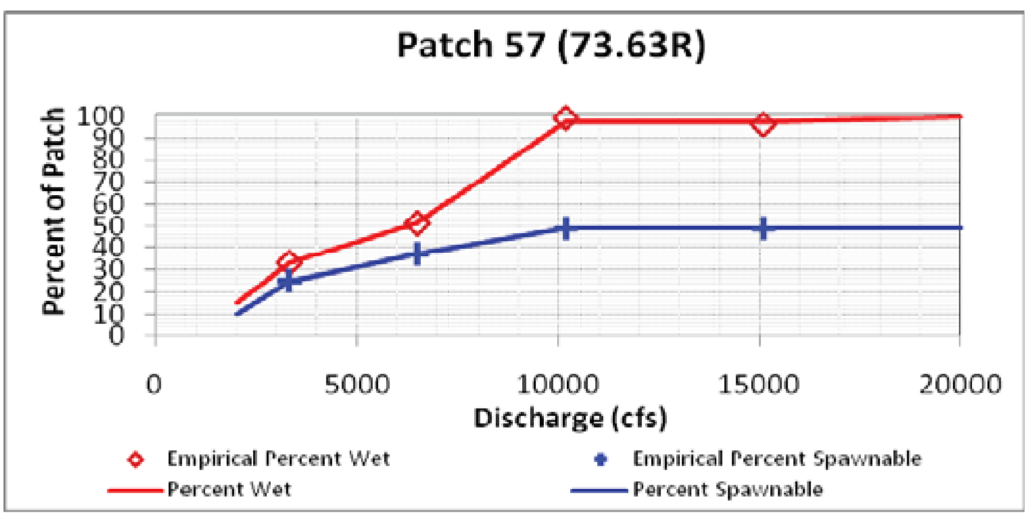


Figure E-20. Empirical Mapping Data and Piece-wise Linear Relationships of the Percent Spawnable and Percent Wet at Patch 58 (73.74R).