The Flow Permanence Index: A Statistical Assessment of Flow Regime in Austin Streams

SR-13-12, July 2013

Abel Porras, P.E., and Mateo Scoggins

City of Austin
Watershed Protection Department
Environmental Resource Management Division

Abstract

Flow permanence or the reliability of baseflow in a stream is an important metric in determining the potential of local streams to support aquatic life and can be used to provide an indication of future ecological changes. This report looks at quantifying the probabilities associated with permanent flow at all streams monitored for the City of Austin Environmental Integrity Index. Spatial patterns in flow permanence were examined, as well as the contributions of rainfall to flow permanence. Among the principal results is an index and ranking of streams with the most and least consistently flowing monitoring sites and a heuristic to calculate the probability of flow in a stream given the cumulative rainfall in the previous three months.

Introduction

The City of Austin (COA) is quickly becoming a major metropolitan city with over 1,000,000 people living within Austin and its surrounding areas (CAMPO, 2010). With this increased urban development, water quantity and quality plays a key role in the ecological health of Austin streams. The impacts of watershed urbanization on aquatic systems including hydrologic and water quality degradation have been previously documented (Leopold, 1968; Klein, 1979; Scoggins, 2000; Olivera and DeFee, 2007; Glick et al, 2010). Hydrologic fluctuations alter the composition and function of aquatic ecosystems (Standford and Ward, 1979; Dynesius and Nilsson, 1994; Bunn and Arthington, 2002; Scoggins, 2000; Glick et al, 2010), and the presence of flow has been demonstrated to be a primary explanatory variable in predicting benthic macroinvertebrate community composition in Austin streams (Richter, 2011). A availability of water is a major limiting factor for riparian vegetation (Richardson et al., 2007), and altered hydrologic regimes change riparian community structure and function (Huddle et al., 2011) thereby reducing the pollutant removal and groundwater infiltration capabilities of riparian zones (Richardson et al., 2007).

Given this research, an inventory of consistently flowing streams may lead to more effective management of urban development to prevent adverse impacts to aquatic and riparian ecosystems of those streams with consistent flow. To guard against future environmental degradation of the streams, the COA is proactive in the monitoring and assessment of Austin's diverse streams. Rigorous data collection on the City's streams began in 1996, providing a substantial existing record which may be used to assess a variety of questions.

Implications and questions about the permanence of Austin streams result from this data collection. Which streams are most likely to be consistently flowing and which are most likely to be continuously dry? Is there a pattern to the consistency of flow in the stream? To what extent does rainfall impact the permanence of the streams? Are there any locations that are more resistant or more susceptible to drought? Can it be determined from the data whether there has been a change in the stream flow over time? What factors influence the permanence of stream flow? Each of these questions can be addressed, either directly or indirectly, by analyzing the field and gauge generated flow data.

Using data collected by the COA, a determination of flow permanence for each stream is examined. This report will look at the probability of whether a given stream reach will be flowing or not flowing based on past records of flow. The contribution of rainfall on the probability of flow is also assessed. In order to do this, the report aims to accomplish the following three objectives:

1. Conduct a probability analysis to determine the gradient of permanent to impermanent flow;
2. Determine whether there is a spatial component to the patterns of permanence or impermanence of flow; and
3. Assess the contribution of cumulative rainfall on flow permanence.

Background

There are currently 51 distinct watersheds as defined by the COA Drainage Criteria Manual, that drain to a named creek or stream that flows through or within the city limits and are monitored by the COA Watershed Protection Department (WPD). Further, each of these streams is partitioned into sections or reaches. Typically, a stream is divided into 2 or 3 sampling reaches, but may be as many as 6 or as few as 1 depending on watershed size and heterogeneity in landscape characteristics.

For the past two decades, WPD has engaged in several monitoring and watershed characterization studies. This includes the Environmental Integrity Index (EII), a program that monitors and evaluates the environmental quality of the city's stream (Hiers, 2002). The EII assigns scores based on water quality parameters and the ecological conditions of the monitored reaches. As part of the EII monitoring program, instantaneous stream flow data was collected for each of the reaches beginning in 1996. This data, combined with data from earlier studies, has resulted in more than 9,000 instantaneous stream flow records in Austin area streams. Instantaneous stream flow (discharge) measurement is typically performed using Marsh-

McBirney electromagnetic velocity meters following Texas Commission on Environmental Quality procedures (TCEQ, 2012) although visual assessments of flow conditions are also performed when instantaneous flow is not physically measured.

Each COA watershed has been designated a three letter code by the COA Drainage Criteria Manual, and within each watershed, a number has been assigned to each sampling section of the stream (also denoted reach) beginning with 1 for the most downstream reach and increasing incrementally for upstream reaches. Thus, the most downstream reach of Barton Creek is assigned the alphanumeric code, BAR1. The next upstream reach is designated BAR2, and so on. There are 126 reaches designated by the EII (Fig 1). Sampling may have occurred in various locations throughout the stream reach, but in looking at whether a reach was perennial or not, all samples within a delineated reach boundary were compiled into one data set.

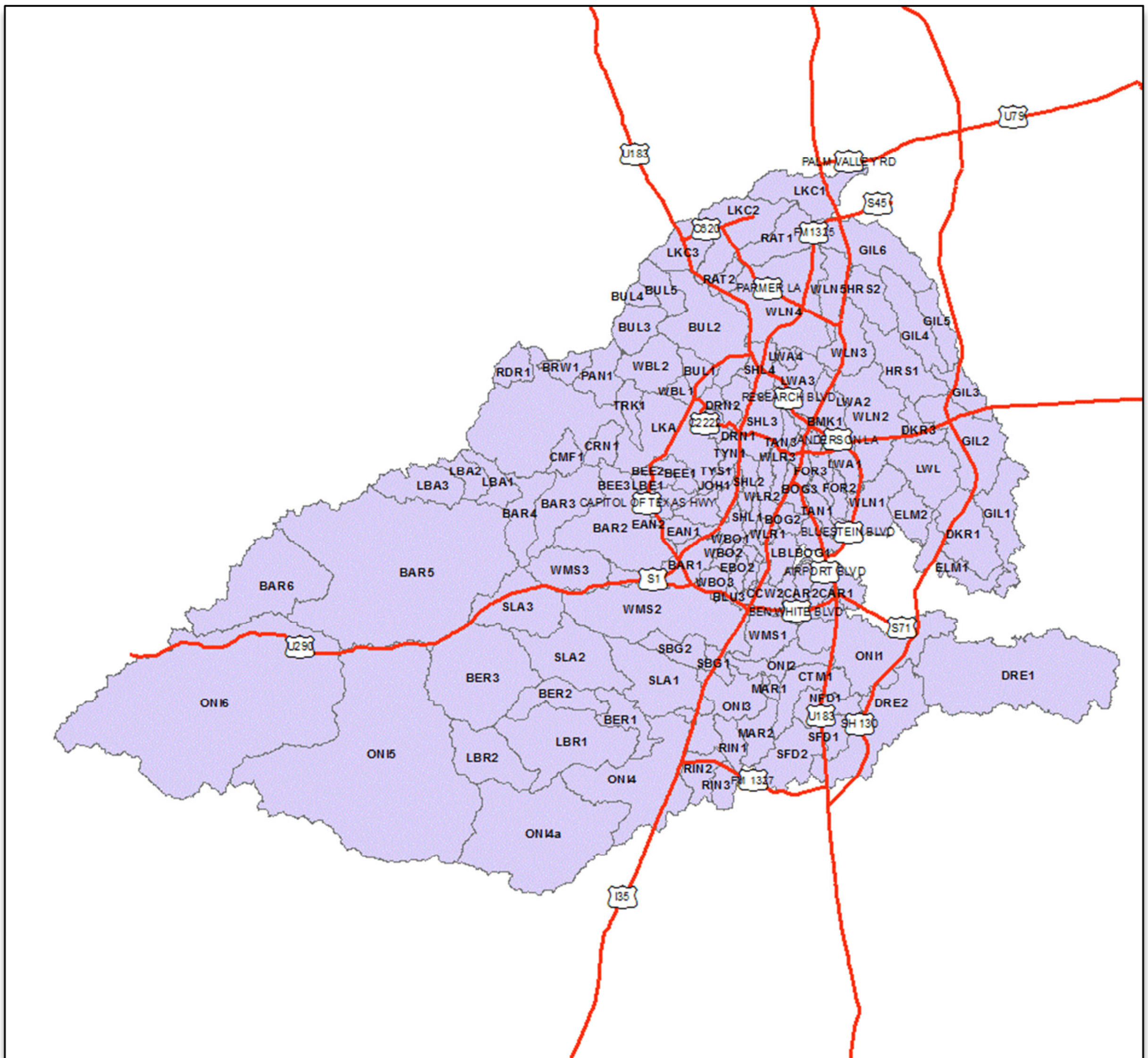


Figure 1: Overall Map of the 126 EII Reaches

Methods

The analysis in this report made use of data from several COA monitoring projects. If flow was not present during the sampling event, this was typically indicated in the records with either a visual flow type assessment parameter value of "N" or a TCEQ (2012) flow severity code of "1" or "6" (a value of "1" indicates no flow but pools present, whereas a value of "6" corresponds to dry conditions). Flow was assumed to be present during a sampling event at the site if that site had a flow severity code of "2", "3", "4", or "5" or a flow measurement greater than 0.01 ft^3/s (cfs).

The data was checked for consistency. In some cases, the database indicated that a water quality sample had been collected, but also had a flow severity code of "1". This might produce a contradiction in the algorithm given above, but since a flow severity code of "1" corresponds to an observation of "pools" in the stream, it was assumed that the measurement was on the pool and was not an indication of flow. Therefore, flow severity had precedence in determining flow occurrence.

Once the data was checked for consistency, each sampling event, or observation, was assigned one of two designations: flowing or not flowing. This binary partitioning enabled a rough calculation of proportion of flowing sites per reach. Thus, each reach will contain a proportion of flow occurrences from 0 to 1.

Theoretical Considerations

While the recording of the presence of flow is straightforward, it is important to realize that there is still a random component to the natural system. Rainfall and groundwater discharge are random variables that affects flow in the stream. Furthermore, there is a possibility of randomness in the measurement or subjectivity of the observation and sampling location and strategy of the reach. It is possible that a location was observed to be dry when upstream or downstream locations could have had low flow. Also, errors could have been committed in the compilation of the data. Dry records could have been unintentionally omitted. When randomness is considered as part of a process where each observation is either "flowing" or "not flowing" from a sampled population of *n* items, statistical intervals for proportions provide a useful metric (this will be discussed in greater detail below). Thus, this report will look at the proportion of flow calculated from the records, and consider this proportion as a *random variable* rather than a known variable.

Since proportion is considered a random variable, drawing any conclusions from the sampled data on flow permanence must be made using statistics. Before statistical analysis can proceed, steps should be taken to insure that the definitions and assumptions used in this report are in accordance with the theory behind the statistics

General Assumptions

The target population, which is total population of interest, will be defined in this report as the finite segments of streams in the COA area (or reaches) every day during the years 1991 to 2012.

The characteristics being sampled are whether flow greater than 0.01 ft^3/s was observed or recorded on every stream for every day. The sampled population is a subset of this target population, and was defined to be every reach on the days that sampling on the stream took place. The data was assumed to be collected by a simple random sampling scheme.

For instance, BAR1 on August 23, 1993, constitutes one item of the target population. BAR1 on August 24, 1993, constitutes another item in the target population. BAR2 on August 23, 1993, was yet another item of the target population. In all, there are approximately 966,000 items in the target population (365.25 days/year x 21 year period x 126 reaches). The sampled population of about 9,000 data points represents a little less than 1% of the target population. However, the assumption that each item of the target population comes from an independent and identical distribution will assist in making statistical inferences on the target population from the smaller sampled population.

Note that the idea of independence among the distributions applies both spatially and temporally. Thus, this report assumes that that the flow determination on August 24 is independent of the flow determination on August 23. Also, it assumes that the flow determination in BAR1 on August 24 is independent of the flow determination in BAR2 on August 24.

Another of the main assumptions used in this report is that the random samples are obtained over a period of time that is representative of the natural system that is being characterized. Since the time period 1991 through 2012 contained periods of extreme drought (2010 – 2012) as well as higher than average rainfall (2004 and 2007), taking samples over this period adequately represents the natural system.

Under these conditions, it appears that an *enumerative study* is required, which is roughly defined as one in which inferences are made on an existing, finite, and specific population based on a random sample. This is in contrast to an *analytic study*, which is roughly defined as one in which a decision is made on the process or cause system and the interest centers on some future process and not in the process being studied (Hahn and Meeker, 1991). Enumerative studies are performed when inferences are made about the sampled data, and analytic studies are performed when inferences are made beyond the sample data. For this report, the enumerative approach was taken; however, the analytic study was mentioned to leave the possibility open for further study in predicting beyond the current data.

Distribution Assumptions

Assumptions on the distribution used in this report require some clarification. Under the conditions listed above, where each observation is either "flowing" or "not flowing" from a sampled population of n items from the target population, statistical intervals for proportions are appropriate (Hahn and Meeker, 1991). The binomial distribution is the underlying framework for intervals on the proportion.

The main thrust of this report is to look at the probabilities of a reach to have permanent flow, not on the true proportion of flow occurrences per reach. Thus, to examine the probability of a reach containing permanent (or impermanent) flow, the cumulative binomial distribution can be used. The Cumulative Binomial Distribution looks at the probability of obtaining *s* or more successes over *n* trials given a random process where the probability of success for each trial is *p*. For this report, *p* will denote the proportion calculated from the data, and *s* will denote the expected number of times flow will occur out of the next *n* sampling events. Thus, the proportion calculated by the intervals will be used to derive the probability of flow permanence.

For a reach to be considered as permanently flowing, it is necessary to first partition the streams into one of three categories: strictly permanent, strictly impermanent, or semi-permanent. A reach will be defined as *strictly permanent* if flow has been observed over 85% of the time[1]. Similarly, a reach will be defined as *strictly impermanent* if no flow has been observed over 85% of the time. Reaches not included in these two categories will be classified as *semi-permanent*.

For this report, *s* and *n* will equal 17 and 20, respectively, for strictly permanent flow. That is, for a reach to be considered strictly permanent, 17 or more occurrences of flow should be detected in the next 20 sampling events. The reach's proportion can then be inserted in the cumulative binomial distribution to produce a probability. If that probability is greater than 50%, then that reach will be considered strictly permanent. Similarly, for a reach to be considered strictly impermanent, the probability of 3 or fewer occurrences of flow should be detected in the next 20 sampling events less than 50% of the time.

Under these guidelines, for a reach which had flow 85% of the time, the probability of that stream being a permanently flowing stream (that is, having the next 17 out of 20 sampling events containing flow) is 68%.

While using 17 out of the next 20 sampling events as a rubric for determining flow permanence might seem arbitrary, it is helpful in many respects. The next 20 sampling events under the EII will look forward approximately 8 years. This is sufficient time to test the statistics calculated here. Second, using 17 out of 20 will lead to about 85% of the flowing events, which seems natural, if a bit liberal, for a reach to be classified as strictly permanent given the aforementioned weather events of the past twenty years.

Statistical Analysis

The statistical analyses used by this report include statistical intervals, geostatistics, and logistic regression. Each provides a different, yet complementary account of flow permanence in Austin's streams.

<u>Statistical Intervals</u>

Data gathered from the various sampling campaigns over the past two decades have provided a sample proportion of flowing reaches in Austin. This sample proportion, p^*, is a point estimate of the true population proportion, *p*. This sample proportion differs from the true proportion due to the sampling variations described above. To ameliorate this discrepancy, a two-sided

[1] The 85% cutoff is an arbitrary designation. However, it allows for reaches with smaller sample sizes to be included in the strictly permanent or strictly impermanent categories.

confidence interval of the proportion can be constructed from the sample data to provide limits on the possible outcome of the true population proportion.

Blyth and Still (1983) provide a calculation method to construct confidence intervals for the true proportion of flowing sites based on the sampled population of streams. This method gives the following equation:

$$[p_l, p_u] = \left[\left\{ 1 + \frac{(n-x+1)\cdot F_{(1-\frac{\alpha}{2};(2n-2x),2x)}}{x} \right\}^{-1}, \left\{ 1 + \frac{(n-x)}{(x+1)\cdot F_{(1-\frac{\alpha}{2};(2n-2x),2x)}} \right\}^{-1} \right] \quad (1)$$

For this equation, n is the total number of times that a site was sampled. The parameter, x, is the number of times that flow was observed at each of the times, and $F_{(1-\alpha/2;\, a,b)}$ are values for the F-Distribution with a and b degrees of freedom. The result is a lower and an upper confidence interval, p_l and p_u, on the true proportion of flowing sites.

While using confidence intervals on the true proportion can provide a helpful ranking of the reaches, this report is looking to determine which reach is strictly permanent and which is strictly impermanent. This determination can be done by using the true proportion of flow calculated at each of the reaches to ascertain the probability for flow permanence for each of the reaches. This is accomplished via the binomial distribution (as discussed earlier):

$$[prob_{L\text{-}PERM}, prob_{U\text{-}PERM}] = [1 - B(17; 20, p_l), 1 - B(17; 20, p_u),] \quad (2)$$

For this equation, $prob_{L\text{-}PERM}$ and $prob_{U\text{-}PERM}$ are the lower and upper confidence intervals, respectively, for the probability that a given reach will contain 17 or greater flow occurrences over the next 20 sampling events. B(17; 20, p_l) is the probability of 17 or fewer flow occurrences over the next 20 sampling events given the lower confidence interval of the true proportion and is computed under the cumulative binomial distribution. Similarly, B(17; 20, p_u) is the probability of 17 or fewer flow occurrences over the next 20 sampling events given the upper confidence interval of the true proportion and also is computed under the cumulative binomial distribution. This, in effect, gives the probability of a reach being strictly permanent, as defined in this report.

Conversely, the equation to obtain the probability of a reach being strictly impermanent is:

$$[prob_{L\text{-}IMP}, prob_{U\text{-}IMP}] = [B(3; 20, p_u), B(3; 20, p_l),] \quad (3)$$

Here, B(3; 20, p_l) is the probability of 3 or fewer flow occurrences over the next 20 sampling events given the lower confidence interval of the true proportion and is computed under the cumulative binomial distribution. Similarly, B(3; 20, p_u) is the probability of 3 or fewer flow occurrences over the next 20 sampling events given the upper confidence interval of the true proportion and also is computed under the cumulative binomial distribution. That the *lower* confidence interval of the probability of impermanence is based on the *upper* confidence interval of the true proportion and the *upper* confidence interval of the probability of impermanence is based on the *lower* confidence interval of the true proportion.

Kriging

While it may be helpful to see the results of the probability of each reach independently, it is also interesting to see how the results might look in relation to one another. Examining the data in this way will also function as a test of spatial independence. Kriging accomplishes these tasks using spatial correlations between the sampling points (Isaaks and Srivastava, 1989). This analysis uses measurements taken at their respective spatial coordinates and provides a prediction surface map of that measurement at every location in the map. Ordinary Kriging is advantageous because it also provides an uncertainty map to examine the bounds of the predictions. Ordinary Kriging is useful in evaluating whether flow (or non-flow) from one site may impact flow (or non-flow) from a nearby site. Measurement data will come from the proportions calculated above, and a continuous prediction map of the proportions can be developed to examine any spatial trends in the data.

Indicator Kriging uses much of the same theoretical construct as Ordinary Kriging (Isaaks and Srivastava, 1989). However, instead of creating prediction surface maps of the measurements, thresholds are chosen by the user, and a prediction surface map of the probability of a sampled site exceeding that threshold is obtained. In this way, probability surface maps can be created to determine which sites are most likely to be strictly permanent (or impermanent) based on the threshold of sites with proportion exceeding 0.85 and based on results from surrounding sites. Additionally, Indicator Kriging avoids many of the strict assumptions of Ordinary Kriging. Both Kriging and Indicator Kriging will be used in examining the flow data, as well as in examining the spatial independence of flow in the reaches

Regression Analysis

Finally, regression analysis will be used to examine the impacts of rainfall on flow permanence. In particular, since the dependent variable (flow) is dichotomous, logistic regression will be utilized. The independent variable used for this analysis is rainfall in Austin. Specifically, the antecedent 3-month, cumulative rainfall total was used and paired with the occurrence of flow for every reach for that month. Thus, the logistic regression used by this report will look at how the 3-month, cumulative rainfall total impacts the presence of flow.

A logistic curve is used to fit the rainfall data with data on reach flow occurrence. This curve fits rainfall total to a number between 0 (no flow) and 1 (flow). This number corresponds to a probability that the reach will have presence of flow given a 3 month cumulative rainfall total. The logistic curve used is:

$$y = \frac{e^{\beta_0+\beta_1 x}}{1+e^{\beta_0+\beta_1 x}} \qquad (4)$$

Using the data, the goal of logistic regression is to solve for the parameters, β_0 and β_1. Inserting the dependent data, represented by *y*, and the independent data, represented by *x*, into the equation, provides a solution to the parameter values. Note that this solution is obtained using a maximum likelihood estimate, since certain restrictions do not apply to logistic regression. This allows a certain amount of freedom in model fitting, but it also restricts the amount of information used (i.e. information on just whether there was flow or not, rather than the amount of flow).

One may manipulate Equation 4 to solve for $e^{\beta_0+\beta_1 x}$ in order to bring a little more clarity to the solution. The resulting manipulation (and subsequently taking the logarithm of the solution) gives:

$$\log\left(\frac{y}{1-y}\right) = \beta_0 + \beta_1 x \qquad (5)$$

Since *y* may be thought of as a probability for flow occurrence and *(1-y)* may be thought of as a probability of no flow occurrence, *y/(1-y)* may be thought of as the odds of flow occurrence. So *log[y/(1-y)]* or the logit function returns the log(odds) of flow occurrence. Both of the equations are equivalent, but Equation 4 is used in the *glm* function from the software program R. This program was used to solve for the parameters for each of the 126 sampled reaches.

Results

The results from the confidence intervals on the true proportion will be given first, followed by confidence intervals on the probabilities of each reach being strictly permanent or strictly impermanent. The results from Kriging and Indicator Kriging analyses will then be displayed. Finally, the results from the logistic regression will be provided.

Confidence Intervals on the True Proportion

Equation 1 was used to determine the confidence intervals on the true proportion of flowing sites. Table 1 shows the fifteen most consistently flowing sites. Table 2 shows the fifteen reaches with the least consistently flowing sites. Within these tables are columns showing the total number of times that a site was sampled, the number of times flow occurred at that site, the sample proportion of flow occurrences to total sites, and the confidence intervals on that true proportion. An index was also calculated to rank sites with nearly equivalent confidence intervals. The index was based on the following formula:

$$\text{Index} = 100 \cdot p_l + 1/[100 \cdot (p_u - p_l)] \qquad (6)$$

This formula simply scores sites higher based on its lower confidence interval and its range. The index also favors those reaches with greater statistical power. Those reaches with the highest number of sampled occurrences had smaller uncertainty and smaller range, and thus, held a higher position in the rankings of flow permanence.

Table 1: The 15 Sites with the Most Consistent Flow

Watershed	Total Number of Site Visits	Number of Flow Occurrences	Proportion	Lower Confidence Interval	Upper Confidence Interval	Index
SHL1	110	110	1.000	0.967	0.999	97.0
WLR1	109	109	1.000	0.967	0.999	97.0
LWA1	72	72	1.000	0.950	0.999	95.2
BUL5	100	99	0.990	0.946	0.999	94.7
ONI4	118	116	0.983	0.940	0.999	94.2
BLU1	107	105	0.981	0.934	0.998	93.6
BUL1	141	137	0.972	0.929	0.999	93.0
ONI3	76	75	0.987	0.929	0.999	93.0
WMS1	88	86	0.977	0.920	0.997	92.2
ONI2	129	124	0.961	0.912	0.999	91.3
ONI1	60	59	0.983	0.911	0.999	91.2
BMK1	60	59	0.983	0.911	1.000	91.2
GIL1	38	38	1.000	0.907	0.999	90.9
GIL2	37	37	1.000	0.905	0.999	90.6
GIL5	37	37	1.000	0.905	0.999	90.6

Table 2: The 15 Sites with the Least Consistent Flow

Watershed	Total Number of Site Visits	Number of Flow Occurrences	Proportion	Lower Confidence Interval	Upper Confidence Interval	Index
CMF1	34	18	0.529	0.351	0.702	35.2
BMK2	32	17	0.531	0.347	0.709	34.8
DRE2	59	27	0.458	0.327	0.592	32.8
CTM1	67	30	0.448	0.326	0.574	32.6
TRK1	34	17	0.500	0.324	0.676	32.5
RAT1	31	15	0.484	0.302	0.669	30.2
WMS3	83	33	0.398	0.292	0.511	29.2
WMS3	83	33	0.398	0.292	0.511	29.2
RIN2	32	15	0.469	0.291	0.653	29.1
LBE1	88	34	0.386	0.284	0.496	28.5
CRN1	33	15	0.455	0.281	0.636	28.1
CCW1	32	14	0.438	0.264	0.623	26.4
WMS2	44	18	0.409	0.263	0.568	26.4
FOR2	33	12	0.364	0.204	0.549	20.4
NFD1	46	15	0.326	0.195	0.480	19.6

The list of all 126 reaches is included in Appendix A. Note that the reaches with the most consistent flow are the urban creeks SHL1 (Shoal Creek) and WLR1 (Waller Creek), which are both located in downtown Austin. This may be an indication of leakage from aging water and wastewater infrastructure or contributions from landscape irrigation.

Confidence Interval on Probability of Strictly (Im)Permanent Flow

Using the results on the confidence intervals of the true proportion of flow permanence, Equations 2 and 3 can now be used to determine whether a reach was strictly permanent or strictly impermanent, respectively. Table 3 shows that 28 reaches have greater than a 50% chance of being strictly permanent. Table 4 shows that 8 reaches have at least a 50% of being strictly impermanent. Note that for reaches to be strictly impermanent, the reach must have a probability of at least 50%, rather than a probability of greater than 50% (as was used for strictly permanent). This is due to the high confidence interval of the true proportion that was calculated in Table 2. This in turn reflects the high uncertainty in the proportion. FOR1 (Fort Branch), for example, has an upper confidence limit of the true proportion of flowing sites to be 0.975. This high limit is due to the lack of data collected in this reach (i.e. it was only sampled once).

Table 3: Reaches with a Greater Than 50% Chance of Being Strictly Permanent

Watershed	Lower Confidence Interval	Upper Confidence Interval
SHL1	0.97	1.00
WLR1	0.97	1.00
LWA1	0.92	1.00
BUL5	0.91	1.00
ONI4	0.89	1.00
BLU1	0.86	1.00
BUL1	0.83	1.00
ONI3	0.83	1.00
WMS1	0.79	1.00
ONI2	0.74	1.00
ONI1	0.74	1.00
BMK1	0.74	1.00
GIL1	0.72	1.00
GIL2	0.71	1.00
GIL5	0.71	1.00
GIL6	0.71	1.00
GIL3	0.69	1.00
WLR2	0.66	1.00
TYS1	0.65	1.00
LKC3	0.64	1.00
WLN3	0.63	1.00
CAR1	0.63	1.00
RIN1	0.59	1.00
WLN2	0.57	0.99
BAR3	0.55	0.89
BUL2	0.54	0.99
WLN1	0.52	0.99
WLN5	0.52	1.00

Table 4: Reaches with at Least a 50% Chance of Being Strictly Impermanent

Watershed	Lower Confidence Interval	Upper Confidence Interval
MAR2	0.00	0.50
BER2	0.00	0.52
CCE1	0.00	0.62
EAN1	0.00	0.66
RIN3	0.00	0.73
WBO1	0.03	0.81
ELM1	0.30	1.00
FOR1	0.00	1.00

Kriging Results

Figure 2 shows a prediction map for the true proportion of flow occurrences given its proximity to other sampled sites from Ordinary Kriging. Figure 1, which displays the entire EII watershed network, appears to show a slight trend in the proportion of flow occurrence with higher proportion sites in the north-west and lower proportion sites in the south-east. This trend is not definite, as there are pockets of lower proportion (light green) in the north-west and pockets of higher flow proportion (blue) in the south-east.

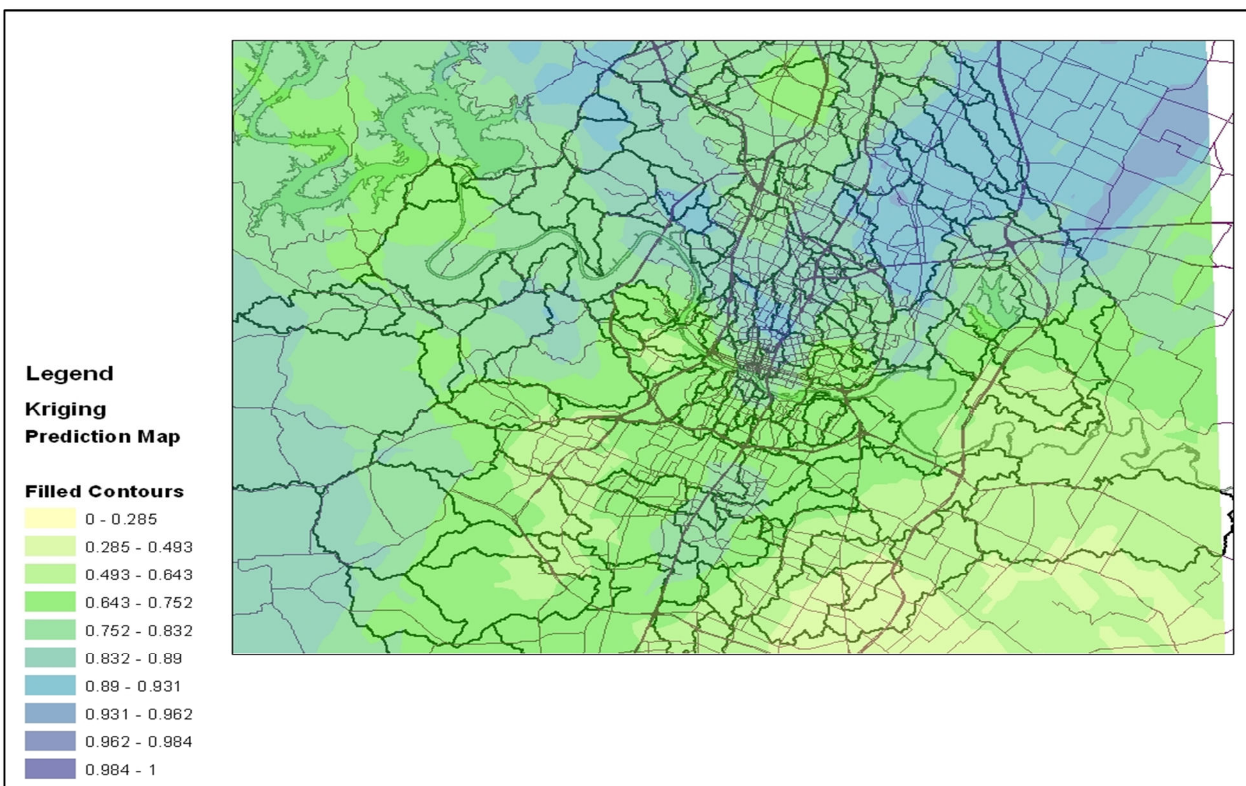


Figure 2: Kriged Map of the Proportion of Flowing Sites

There were predicted low proportion flow occurrences in downtown Austin, despite the fact that the two highest proportion flow occurrences were the mouths of Shoal and Waller Creek where they drain to Lady Bird Lake (Figure 3). The downstream reach of Shoal Creek has a predicted proportion of around 0.49 to 0.64, despite having 110 flow occurrences out of 110 site visits. A semivariogram (a plot of the spatial correlation versus distance) shows that the difference between the kriged model (the dark blue line) and the correlations (the red dots) increase as distance increases (Figure 4). This indicates that the errors are increasing as distance increases, which violate the model assumptions.

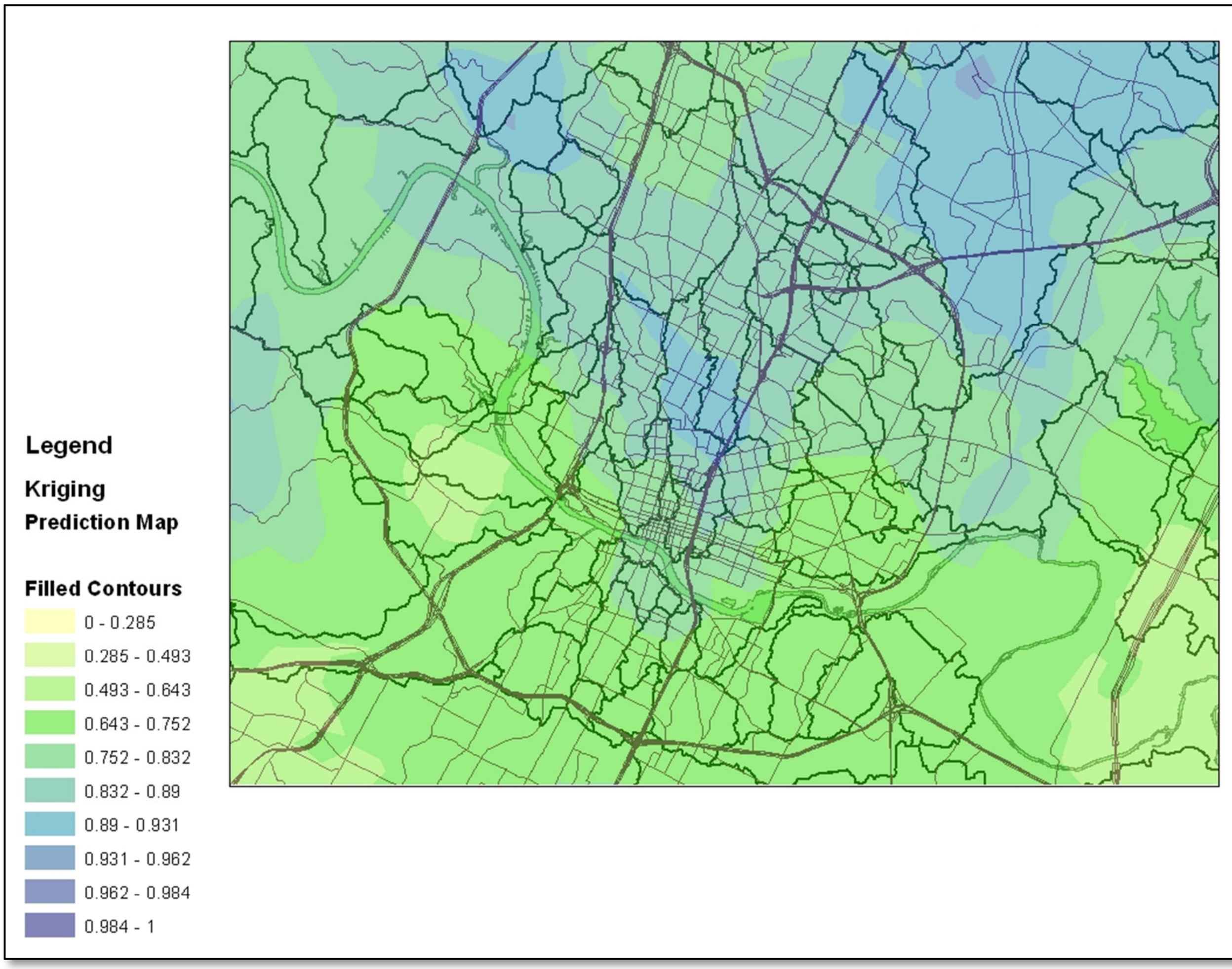


Figure 3: Kriged Map of the Proportion of Flowing Sites (Close up of Downtown Austin)

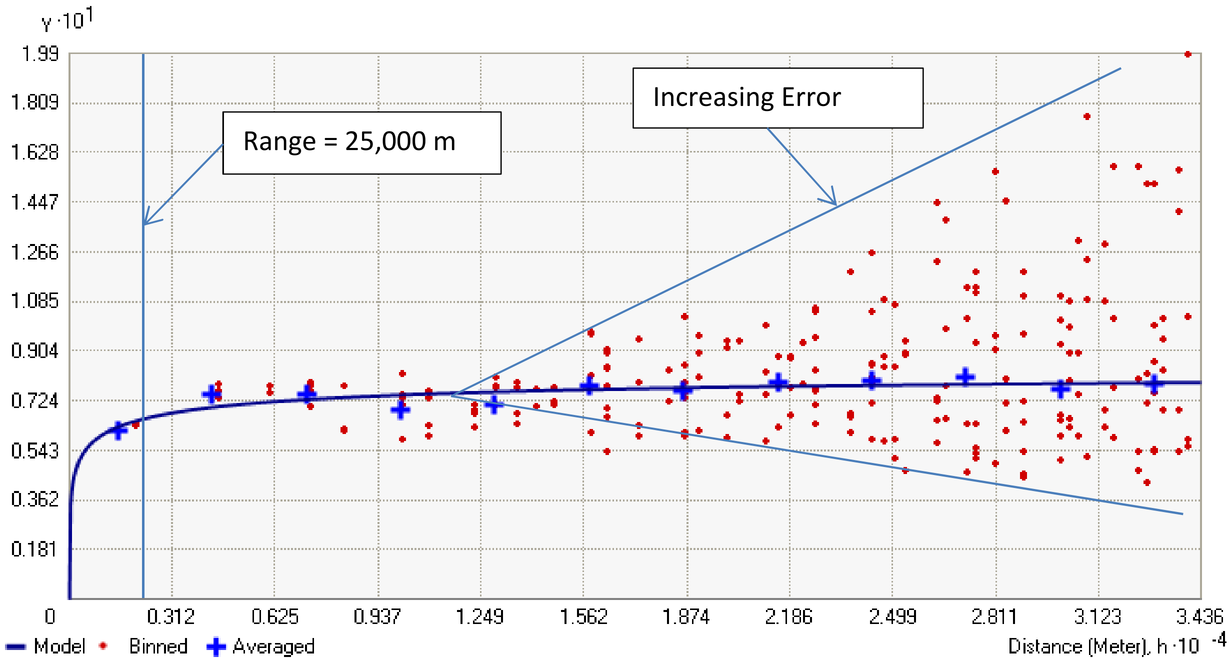


Figure 4: Semivariogram Using Ordinary Kriging.

The semivariogram also indicates that the location on the x-axis where the model no longer increases is at 25,000 meters. This indicates that points equal to or less than 25,000 meters (or 15 miles) are correlated. This is clearly erroneous. So a less restrictive spatial model (i.e. Indicator Kriging) is required.

The Indicator Kriging semivariogram (Fig. 5) shows more consistent errors with increasing distance. It shows that points equal to or less than 3000 meters (1.9 miles) have some level of correlation suggesting a better model.

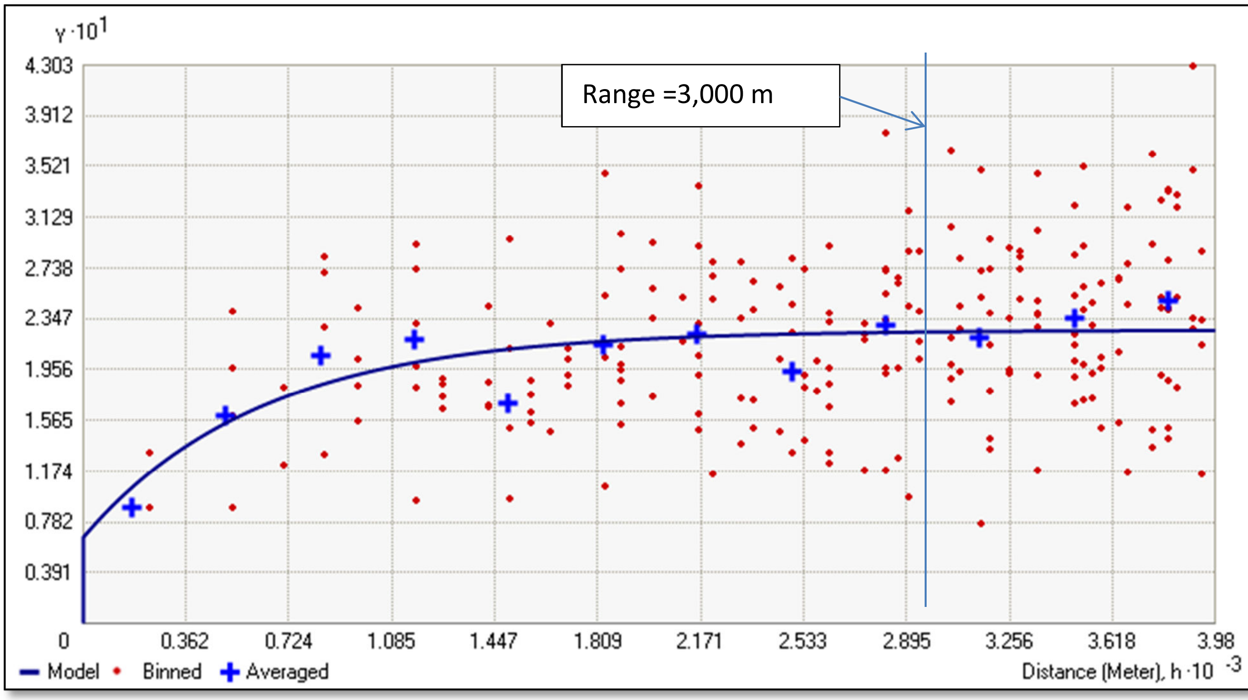


Figure 5: Semivariogram Using Indicator Kriging with a Threshold of 0.85.

Figure 6 provides an overall view of the EII watershed network and Figure 7 is a close-up of the downtown area. The cooler the colors in Figure 6, the less probability of the reach being strictly impermanent. Note that most of the prediction map has a cool color. Elm Creek stands out as having a high probability of being strictly impermanent given its proximity to other sites (right side of Figure 6). Similarly, downstream reaches of Fort Branch, Decker, Dry Creek East, and West Bouldin and the upper reaches of Little Bear and Walnut Creek show high probabilities of being strictly impermanent (orange and red colors, Fig 6 and 7).

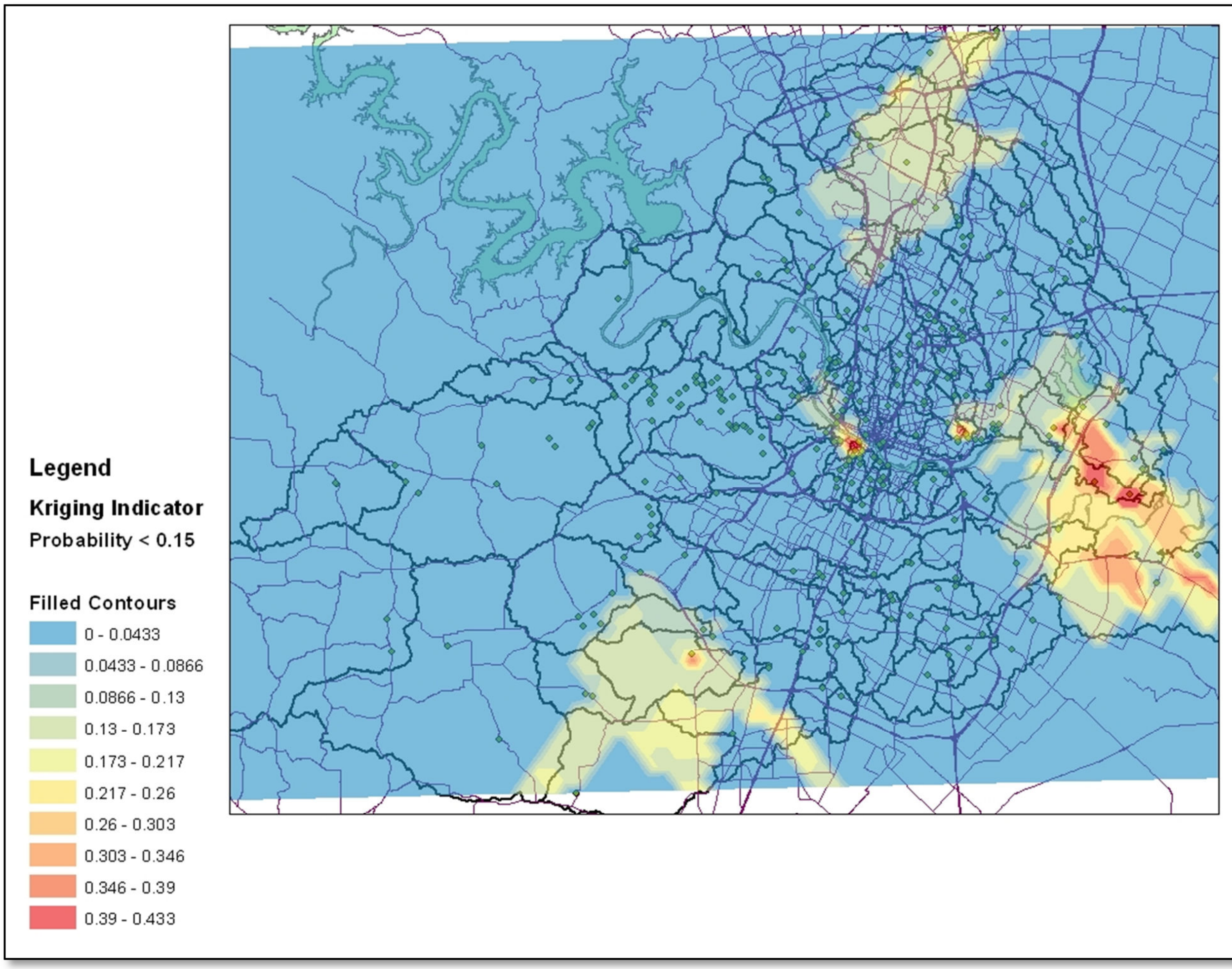


Figure 6: Probability of Strictly Impermanent Reaches in Austin.

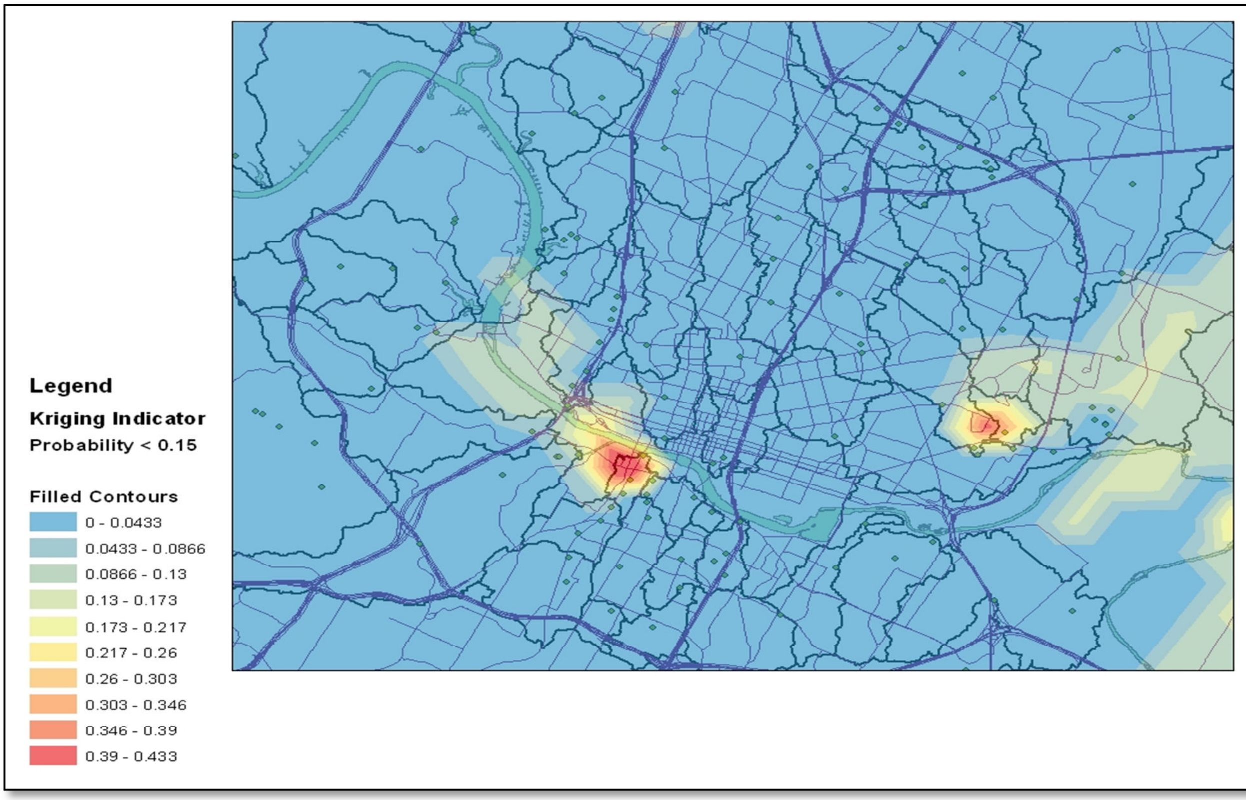


Figure 7: Probability of Strictly Impermanent Reaches, showing the downstream reaches of West Bouldin and the Fort Branch in warm colors.

The prediction maps of strictly permanent reaches in Austin (Figures 8 and 9) show more variation than the prediction maps for impermanent reaches, and points to the greater probability of streams in Austin being strictly permanent versus strictly impermanent. Figures 5 and 6 showed little chance of a majority of the streams being impermanent whereas Figures 7 and 8 show at least some chance of a majority of the streams being strictly permanent. Figure 7 shows low probability of strictly permanent streams in the east and the south with a pocket in the upper reaches of Walnut Creek. The highest probability of strictly permanent streams occurs in downtown Austin (Fig 8), further north, and along the south west.

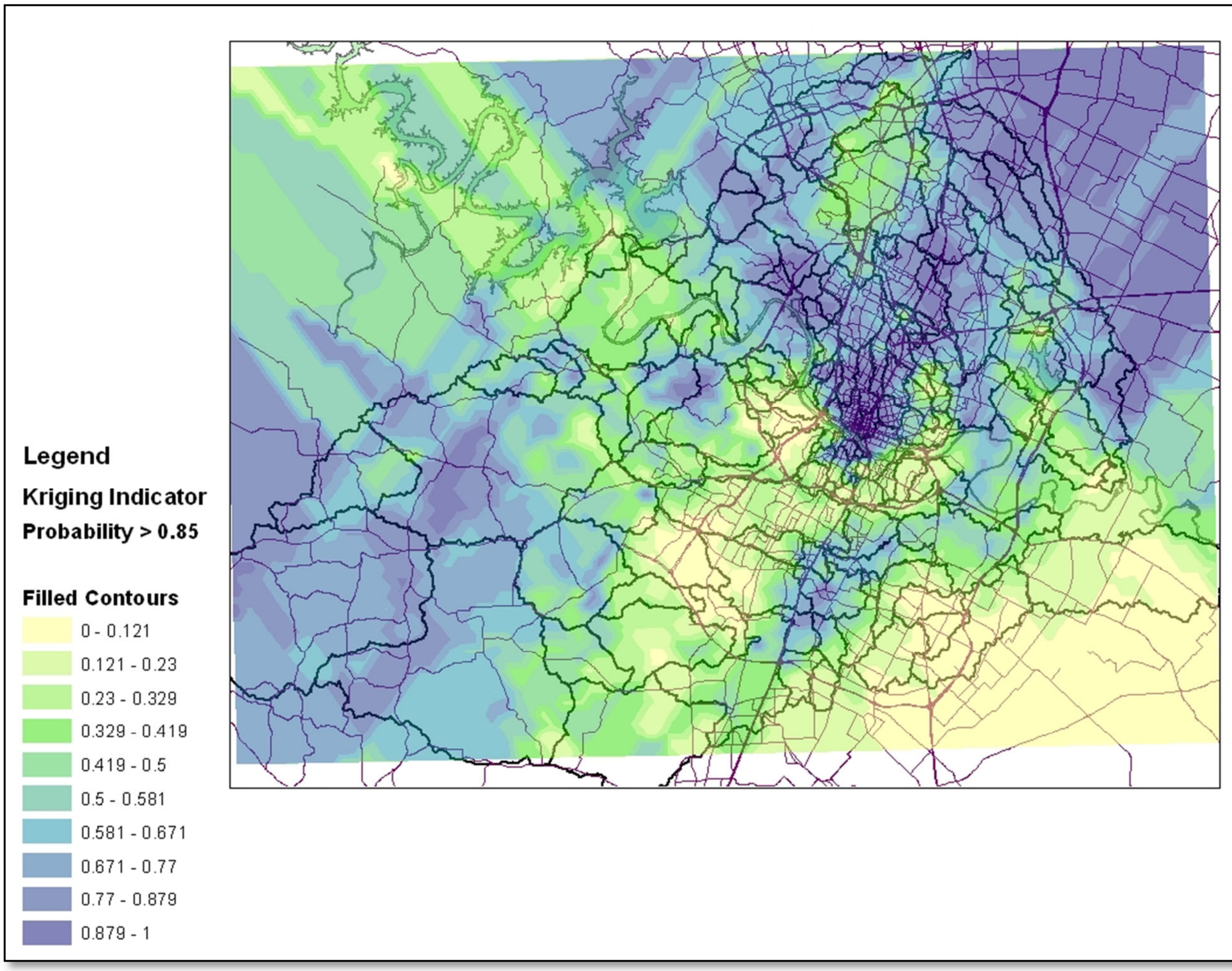


Figure 8: Probability of Strictly Permanent Reaches in Austin, where cooler/darker colors indicate higher probability of permanence.

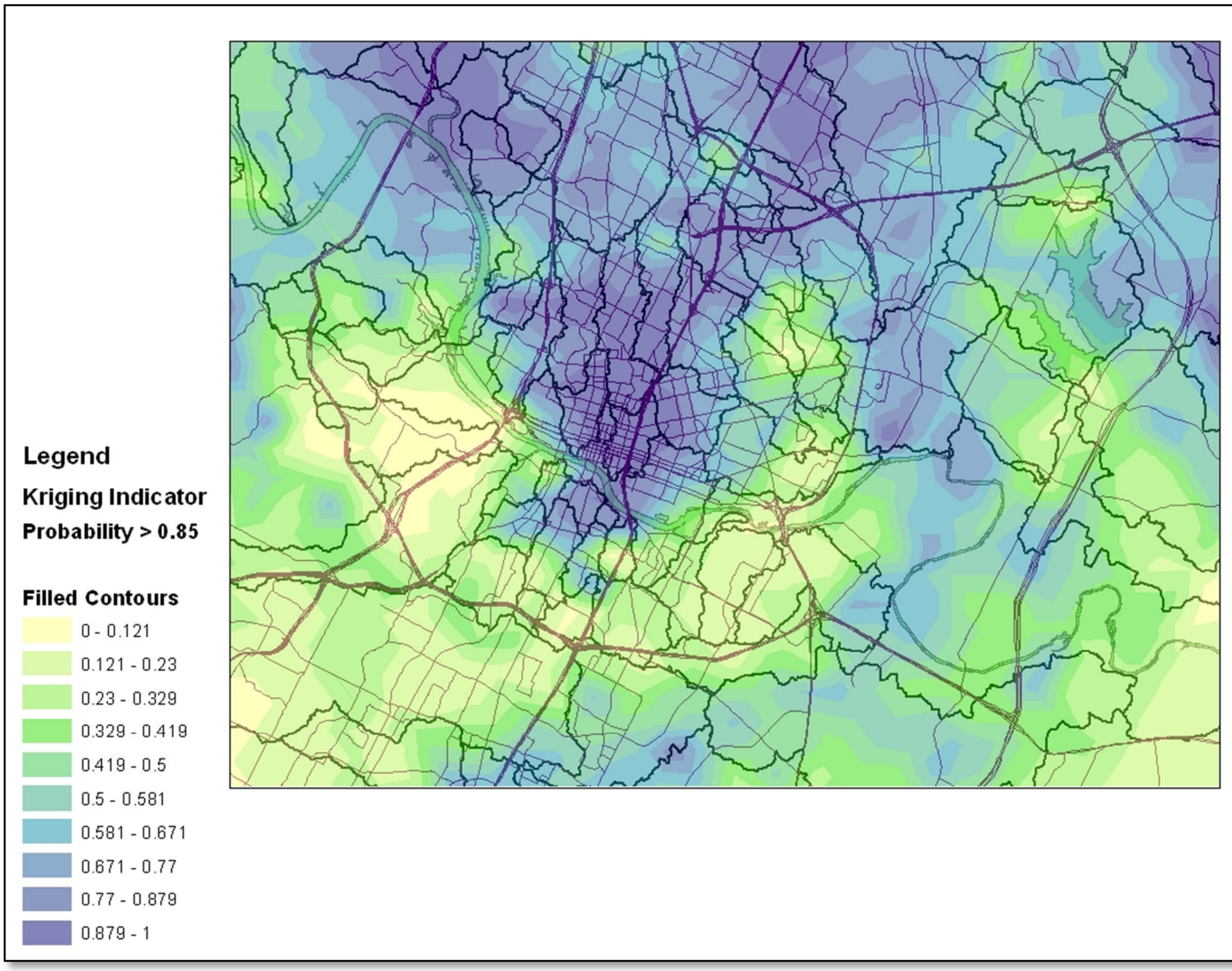


Figure 9: Probability of Strictly Permanent Reaches (Close-Up of Downtown Austin)

<u>Logistic Regression Results</u>

Logistic regression was conducted to show the impact of rainfall on the presence or absence of flow. The parameters β_0 and β_1, were solved using logistic regression. The results for all 126 of the EII reaches are included as Appendix B. Given these parameter solutions and an amount of cumulative rainfall, the probability of flow at any reach may be estimated.

The parameter, β_0, is often deemed to represent the "intercept" of the logistic or logit curve. From equation 5, the intercept (i.e. at $x = 0$), sets the $log[y/(1-y)]$ equal to β_0. Similarly, the parameter, β_1, is often seen as the slope of the logit curve.

Table 5 exhibits the watershed reaches with the 25 largest intercepts, indicating a lack of relationship between flow and rainfall. Looking at the column for the exponential of the intercept, or $e^{\beta o}$, the odds (3.447E11 to 1) for GIL1, indicating that the reach is permanently flowing even with no cumulative rainfall in the previous three months. The reason these numbers are so large is due to the fact that over the past 19 years, flow has been recorded for every single sampling event due to multiple permitted wastewater discharges to the stream. Nevertheless, the intercept can be used as a proxy for flow permanence. Towards the bottom of Table 5, the odds become less astronomical. For BMK1, the odds of that reach having flow given zero rainfall in the past three months was only 125.7 to 1.

Table 5: A List of the 25 Reaches with the Highest Intercept

Watershed Reach	Intercept β_0	Slope β_1	exp(Int) $e^{\beta o}$	exp(Slope) e^{β_1}
GIL1	26.66	-5.45E-14	3.447E+11	1
WLR1	26.66	-5.55E-11	3.447E+11	1
BUL1	26.566	7.51E-11	3.447E+11	1
LWA1	26.566	3.84E-12	3.447E+11	1
ONI4	26.566	7.38E-10	3.447E+11	1
SHL1	26.561	6.06E-11	3.43E+11	1
GIL2	25.566	-1.60E-10	1.268E+11	1
GIL3	25.566	-2.96E-07	1.268E+11	1
GIL5	25.566	-1.60E-10	1.268E+11	1
GIL6	25.566	-1.60E-10	1.268E+11	1
LWA3	25.566	-4.47E-10	1.268E+11	1
ONI1	25.566	-4.64E-11	1.268E+11	1
WLN5	25.566	4.01E-10	1.268E+11	1
WLR2	25.566	1.74E-18	1.268E+11	1
BUL3	25.566	1.00E-17	1.268E+11	1
BUL5	25.566	4.37E-12	1.268E+11	1
CAR1	25.566	1.27E-17	1.268E+11	1
LKC3	25.566	2.49E-17	1.268E+11	1
ONI2	25.566	6.72E-13	1.268E+11	1
ONI3	25.566	1.07E-10	1.268E+11	1
BUL4	24.566	3.14E-10	4.665E+10	1
LWA2	11.052	-0.712	63042.533	0.491
BMK1	4.834	-0.102	125.772	0.903
BUL2	4.002	-0.071	54.683	0.931

Table 6 shows the 10 reaches with the smallest intercept, indicating they had the smallest odds of having flow given zero total rainfall in the past three months. Note that FOR1 has a slope parameter estimate of "N/A" since it only had a sample size of 1. Also note that the magnitude of the intercept is not an indicator of flow permanence. It is simply an indicator of flow given zero rainfall in the past three months. Low odds in the intercept column do not preclude the reach from being strictly permanent.

Table 6: A List of the 10 Reaches with the Smallest Intercept

Watershed Reach	Intercept β_0	Slope β_1	exp(Int) $e^{\beta o}$	exp(Slope) e^{β_1}
WBO1	-1.980	0.056	0.138	1.058
BMK2	-2.047	0.371	0.129	1.449
LBE1	-2.182	0.178	0.113	1.195
WMS3	-2.655	0.250	0.070	1.284
CRN1	-2.675	0.360	0.069	1.433
ELM1	-4.159	0.265	0.016	1.303
BEE3	-6.507	3.326	0.001	27.835
RIN1	-7.153	4.469	0.001	87.257
FOR1	-22.57	NA	1.584E-10	NA
WBL1	-78.00	26.60	1.33E-34	3.57E+11

The inferences from the slopes of the logistic or logit curve with the largest slope indicate how quickly a reach may respond to rainfall from the previous three months. (Table 7)

Table 7: A List of the 10 Reaches with the Largest Slope

Watershed Reach	Intercept β_0	Slope β_1	exp(Int) $e^{\beta o}$	exp(Slope) e^{β_1}
WBL1	-78.003	26.601	0.000	3.57E+11
RIN1	-7.153	4.469	0.001	87.257
BEE3	-6.507	3.326	0.001	27.835
MAR1	-1.468	1.389	0.230	4.012
BRW1	-0.351	0.457	0.704	1.580
SLA1	-1.522	0.427	0.218	1.533
BMK2	-2.047	0.371	0.129	1.449
CRN1	-2.675	0.360	0.069	1.433
BEE1	-0.752	0.340	0.472	1.405
PAN1	-1.101	0.304	0.333	1.355

Thus, looking at the slope, e^{β_1}, for RIN1, one may infer that for every inch of cumulative rainfall over the past three months, the odds of flow at that reach increase by a factor of 87.25. This suggests a rapid recovery to baseflow, or background condition for RIN1, and may be an indication of its small watershed area and corresponding short time of concentration. Slopes closer to one imply that reaches respond more slowly to rainfall and slopes less than one indicate that as the 3 month cumulative rainfall total increases, the odds of flow at that reach drop. This would not occur naturally, and only two of the reaches have slopes significantly less than one. Any reach with a slope greater than 0.9 can be considered (due to sampling errors and uncertainty) to be close to one. ONI4a and LWA2 had slopes of 0.816 and 0.491, respectively. Both of these reaches had a zero flow measurement at a time when the 3 month cumulative rainfall total was high. Whether this is an outlier or simply an error is unknown at this time.

Note that the exponential slope for WBL1 is a large number ($3x10^{11}$), but the exponential intercept is 0. Thus, even though the exponential intercept gives the odds of flow permanence being zero, the exponential slope indicates that it is quick to respond to rainfall. This highlights the importance of considering the parameters in combination, rather than independently when making inferences on the reach. The following example will provide guidance in looking at both parameters in determining the probabilities of reach flow due to rainfall.

The reach BEE1 is used here as an example of flow permanence probabilities. Each of the blue diamonds in Figure 9 represents a sampling event throughout the 21 year sampling period. For each sampling event, the amount of cumulative rainfall over the previous three months was paired with that flow determination (1 for flow, 0 for no flow). Note that sometimes, a low rainfall amount resulted in positive flow and at other times in no flow.

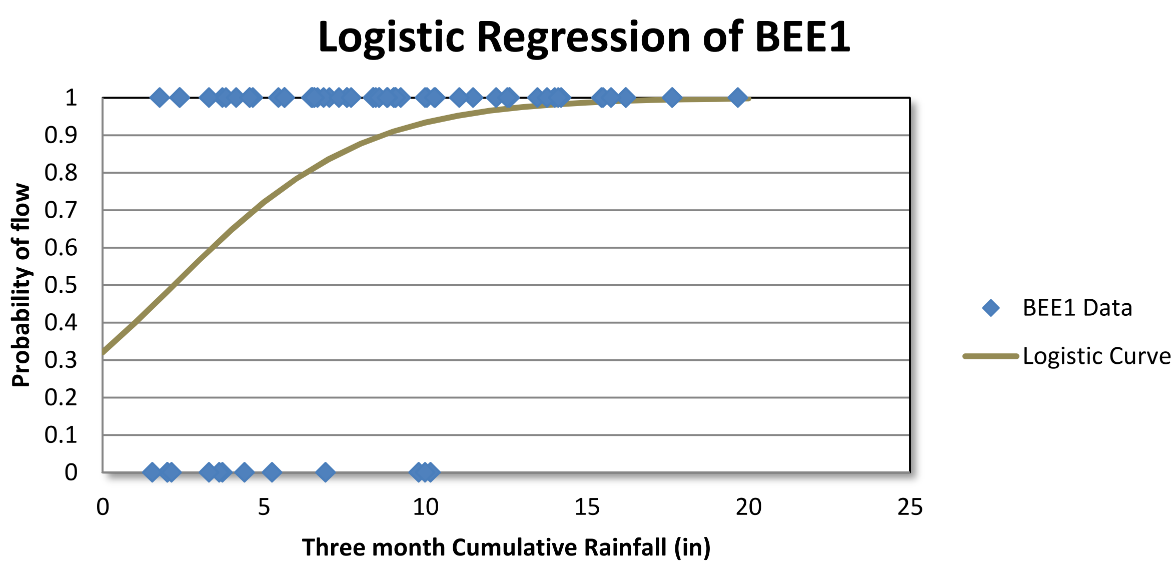


Figure 10: Logistic Regression Curve of BEE1

As the rainfall amount increases the density of 1's also increases. This pattern is well-suited for logistic regression. This pattern where low values are present in the low to middle range of the x-axis and higher values are present throughout the range of the x-axis would have been problematic for linear regression.

The logistic curve represents the probability for flow given the BEE1 rainfall data along the x-axis. Given this data, one would expect higher probabilities of positive flow for higher rainfall amounts and vice versa. Using Equations 4 and 5, Table 8 below shows the results from the logistic regression analysis, and the equation for the BEE1 logistic curve is:

$$y = \frac{e^{-0.752+0.340x}}{1+e^{-0.752+0.340x}} \qquad (6)$$

This equation can be re-written as:

$$y = \frac{e^{-0.752}(e^{0.340})^x}{1+e^{-0.752}(e^{0.340})^x} = \frac{0.47155 \cdot 1.40498^x}{1+0.47155 \cdot 1.40498^x}$$

Inputting a cumulative rainfall amount for *x* into Equation 7 will give a probability of flow. Table 7 uses a 1" three month cumulative rainfall, which results in a 40% probability of flow at BEE1. The reader can now apply this heuristic to compute probabilities ($e^{\beta o}$ and e^{β_1}) for any reach (Appendix B). Note that Appendix B gives the values of $e^{\beta o}$ and e^{β_1}. Thus, the reader may simply multiply the exponentials to arrive at the probabilities.

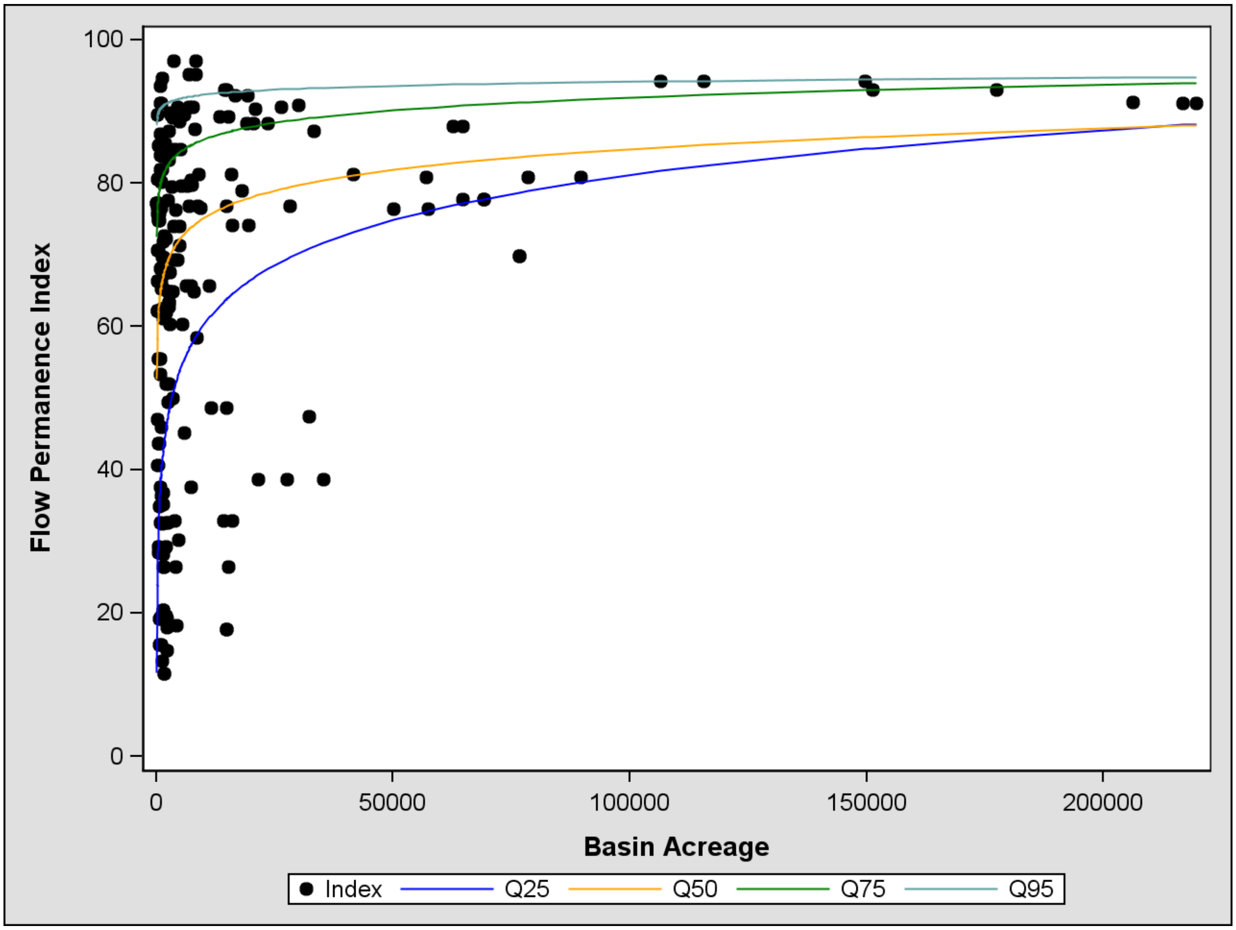
Table 8: Parameters for the Logistic Regression of BEE1 Data

Watershed Reach	Intercept B_0	Slope B_1	exp(Int) $e^{\beta o}$	exp(Slope) e^{β_1}	3-Mo Cumulative Rainfall (in)	Odds of Flow	Probability of Flow
BEE1	-0.752	0.340	0.47155	1.40498	1	0.663	0.399

Quantile Regression with Drainage Area

A quantile regression analysis was also performed on the data[2]. This analysis looked at the relationship between drainage area and flow permanence index, as calculated by Equation 6 (Figure 10).

Figure 10: Quantile regression of Flow Permanence Index by drainage area of each EII reach



By partitioning the flow permanence index among the different quartiles, different regression curves for each quartile can be calculated. The regression curves for the 25th, 50th, and 75th percentiles (in colored lines) all show an increase in the flow permanence index score as their respective contributing drainage area increases. However, data from the 95th percentile of flow permanence does not show any impact due to the increase in drainage area. Statistically, this was done by regressing the natural logarithm of the drainage area with the flow permanence index. Results from the model show that the natural logarithm of the drainage area significantly affects flow permanence index with a p-value of less than 0.0007 for the 25th, 50th, 75th, and 90th percentiles. For the 95th percentile, the results fail to reject the assumption of a non-significant

[2] with contributions from Aaron Richter, COA WPD Analyst.

effect of the natural logarithm of the drainage area on the flow permanence index with a p-value of 0.3614. This indicates that drainage area does not affect index scores that are in the top 5% (a flow permanence index greater than 93).

Conclusion

Determining the flow permanence of Austin's streams can be useful in ranking each of the streams along a potentially important continuum, informing the ecological health assessment of the streams and could be useful in identifying trends over time or space. Using flow and rainfall data collected in the past 21 years, three analyses were conducted to determine flow permanence.

Confidence intervals were constructed on the true proportion of data for each reach in which flow was detected. From these intervals, a Flow Permanence Index was calculated and the probability of each of these streams having flow during 17 of the next 20 sampling events was computed. Any reach which had a greater than 50% probability of having flow at 17 out of 20 observations was classified as *strictly permanent*. Intervals for the probability of each of these streams to contain flow for at most 3 of the next 20 samples were also computed. Any reach with at least a 50% probability of having a maximum of 3 out of 20 positive flow observations were determined to be *strictly impermanent*.

Surface prediction maps (Ordinary and Indicator Kriging) were created to see if there was any spatial pattern to flow permanence or flow impermanence. Generally, reaches to the east and south were found to be more likely to be strictly impermanent than those in the north and west. However, this analysis appeared to give the weakest results of the three, due to uncertainty in spatial correlations. It did point to certain spatial anomalies, provoking questions about other potentially important factors (e.g., a subsurface feature) and their influence on stream flow characteristics.

The impact of rainfall on the reach's permanence was also analyzed. A logistic curve was fit to the data for each of the reaches that can be used compute the probability (or odds) of flow occurring given the previous 3 months rainfall.

The analyses conducted in this report can be considered a first step in analyzing flow conditions in Austin's streams. These analyses can be expanded to include predictions on the range of flow occurrences in the future and any deviation from these predictions can be further investigated. The impact of future rainfall can also be used to investigate whether certain spatial or temporal trends exist. Furthermore, the flow permanence index (Appendix A.1) can be used as a factor in examining differences in biota or as a proxy for other watershed characteristics.

References

1. Blyth, C.R. and H. A. Still. (1983). Binomial Confidence Intervals. Journal of the American Statistical Association 81: 843-855.

2. Bunn, S.E. and A.H. Arthington. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management 30(4): 492-507 pp.

3. CAMPO. 2010. CAMPO 2035 Regional Transportation Plan as Adopted May 24, 2010. Capital Area Metropolitan Planning Organization.

4. Dynesius, M. and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. Science 266: 753-762 pp.

5. Glick, R., L. Gosselink, B. Bai and C. Herrington. 2010. Impacts of Stream Hydrologic Characteristics on Ambient Water Quality and Aquatic Health in the Austin, Texas Area. City of Austin, Watershed Protection Department. SR-10-18.

6. Hahn, G. J., and W. Q. Meeker. (1991) Statistical Intervals: A Guide for Practioners. John Wiley and Sons, Inc. New York.

7. Hiers, Scott. 2002. Environmental Integrity Index Methodology. City of Austin, Watershed Protection Department. COA-ERM-1999-01.

8. Huddle, J. A., Tala, A., Martin, D. L., Zhou, X., Pegg, S. E., and Josiah, S. J. 2011. Do Invasive Riparian Woody Plants Affect Hydrology and Ecosystem Processes. Great Plains Research, 21:49-71.

9. Isaaks, E.H., and R.M. Srivastava. 1989. Applied Geostatistics. Oxford University Press, New York.

10. Klein, R.D. 1979. Urbanization and Stream Quality Impairment. Water Resources Bulletin 15:948-963.

11. Leopold, L.B. 1968. The Hydrologic Effects of Urban Land Use: Hydrology for Urban Land Planning – A Guidebook of the Hydrologic Effects of Urban Land Use. USGS Circular 554.

12. Olivera, F., and B.B. Defee. 2007. Urbanization and its effect on runoff in the Whiteoak Bayou Watershed, Texas. Journal of the American Water Resources Association 43(1): 170-182.

13. Richardson, M. D., Holmes, P. M., Esler, K. J., Galatowitsch, S. M., Stromberg, J. C., Kirkman,S. P., Pysek, P., and Hobbs, R. J. 2007. Riparian vegetation: degradation, alien plant invasion, and restoration prospects. Diversity and Distributions, 13: 126-139.

14. Richter, Aaron. 2011. Linking Biologic Metrics to Hydrologic Characteristics in Austin, Texas Streams. City of Austin, Watershed Protection Department. SR-11-15.

15. Scoggins, Mateo. 2000. Effects of Hydrology on Bioassessment in Austin, Texas. City of Austin,Watershed Protection Department.SR-00-02.

16. Standford, J.A. and J.V. Ward. 1979. Stream regulation in North America. Pages 215-236 in J.V. Ward and J.A. Stanford editors. The ecology of regulated streams. Plenum Press, New York.

17. Texas Commission on Environmental Quality (TCEQ). 2012. Surface Water Quality Monitoring Procedures, Volume 1: Physical and Chemical Monitoring Methods. RG-415.

Appendix A

Table A.1: A Listing of All Watershed Reaches by Index Score

Watershed	Total Number of Site Visits	Number of Flow Occurrences	Proportion	Lower Confidence Interval	Upper Confidence Interval	Index
SHL1	110	110	1.000	0.967	0.999	97.0
WLR1	109	109	1.000	0.967	0.999	97.0
LWA1	72	72	1.000	0.950	0.999	95.2
BUL5	100	99	0.990	0.946	0.999	94.7
ONI4	118	116	0.983	0.940	0.999	94.2
BLU1	107	105	0.981	0.934	0.998	93.6
BUL1	141	137	0.972	0.929	0.999	93.0
ONI3	76	75	0.987	0.929	0.999	93.0
WMS1	88	86	0.977	0.920	0.997	92.2
ONI2	129	124	0.961	0.912	0.999	91.3
ONI1	60	59	0.983	0.911	0.999	91.2
BMK1	60	59	0.983	0.911	1.000	91.2
GIL1	38	38	1.000	0.907	0.999	90.9
GIL2	37	37	1.000	0.905	0.999	90.6
GIL5	37	37	1.000	0.905	0.999	90.6
GIL6	37	37	1.000	0.905	0.999	90.6
GIL3	36	36	1.000	0.903	0.999	90.4
WLR2	34	34	1.000	0.897	0.999	89.8
TYS1	108	103	0.954	0.895	0.985	89.6
LKC3	33	33	1.000	0.894	0.999	89.5
WLN3	105	100	0.952	0.892	0.984	89.3
CAR1	32	32	1.000	0.891	0.999	89.2
RIN1	60	58	0.967	0.885	0.996	88.6
WLN2	118	111	0.941	0.882	0.976	88.3
BAR3	346	316	0.913	0.879	0.941	88.0
BUL2	90	85	0.944	0.875	0.982	87.6
WLN1	109	102	0.936	0.872	0.974	87.3
WLN5	27	27	1.000	0.872	0.999	87.3
BUL4	63	60	0.952	0.867	0.999	86.8
BUL3	67	63	0.940	0.854	0.999	85.5
BEE3	35	34	0.971	0.851	0.999	85.2
LWA2	34	33	0.971	0.847	0.999	84.7
BOG2	33	32	0.970	0.842	0.999	84.3
WLR3	77	71	0.922	0.838	0.971	83.9
DRN1	32	31	0.969	0.838	0.999	83.8
MAR1	58	54	0.931	0.833	0.981	83.3
EBO1	97	87	0.897	0.819	0.949	81.9

BAR5	434	368	0.848	0.811	0.880	81.2
LKC2	51	47	0.922	0.811	0.978	81.2
ONI5	64	58	0.906	0.807	0.965	80.8
DRN2	49	45	0.918	0.804	0.977	80.5
LBA1	56	51	0.911	0.804	0.970	80.4
WBL2	55	50	0.909	0.800	0.970	80.1
SHL2	33	31	0.939	0.798	0.993	79.8
HRS1	60	54	0.900	0.795	0.962	79.6
LWA3	16	16	1.000	0.794	0.999	79.5
LKC1	52	47	0.904	0.790	0.968	79.0
LKA	231	193	0.835	0.781	0.881	78.2
BAR2	936	752	0.803	0.776	0.828	77.8
HRS2	36	33	0.917	0.775	0.982	77.6
HRP1	124	105	0.847	0.771	0.905	77.2
ONI6	80	69	0.863	0.767	0.929	76.8
WLN4	52	46	0.885	0.766	0.956	76.6
TAN3	28	26	0.929	0.765	0.991	76.5
BAR4	198	163	0.823	0.763	0.874	76.4
BAR6	129	108	0.837	0.762	0.896	76.3
BLU2	39	35	0.897	0.758	0.971	75.8
FOR4	33	30	0.909	0.757	0.981	75.7
LWA4	32	29	0.906	0.750	0.980	75.0
EBO2	83	70	0.843	0.747	0.914	74.8
SLA1	76	64	0.842	0.740	0.916	74.1
SHL3	36	32	0.889	0.739	0.969	74.0
RDR1	98	80	0.816	0.725	0.887	72.6
BEE1	75	62	0.827	0.722	0.904	72.2
BRW1	33	29	0.879	0.718	0.966	71.8
LBA2	37	32	0.865	0.712	0.955	71.3
BLU3	58	48	0.828	0.706	0.914	70.6
BAR1	307	230	0.749	0.697	0.797	69.8
TAN2	52	43	0.827	0.697	0.918	69.7
WBL1	43	36	0.837	0.693	0.932	69.3
CCW2	33	28	0.848	0.681	0.949	68.1
EAN2	33	28	0.848	0.681	0.949	68.1
ONI4a	15	14	0.933	0.681	0.998	68.1
SBG1	56	45	0.804	0.676	0.898	67.6
JOH1	137	102	0.745	0.663	0.815	66.4
DKR1	49	39	0.796	0.657	0.898	65.7
CAR2	52	41	0.788	0.653	0.889	65.3
BER3	65	50	0.769	0.648	0.865	64.9
TAN1	49	38	0.776	0.634	0.882	63.4
LBA3	38	30	0.789	0.627	0.904	62.7
WBO2	51	39	0.765	0.625	0.872	62.5

BOG3	44	34	0.773	0.622	0.885	62.2
SBG2	47	36	0.766	0.620	0.877	62.0
SHL4	33	26	0.788	0.611	0.910	61.1
SLA3	92	65	0.707	0.602	0.797	60.3
BOG1	96	66	0.688	0.585	0.778	58.5
TYN1	99	65	0.657	0.554	0.749	55.5
FOR3	32	23	0.719	0.533	0.863	53.3
LBR2	31	22	0.710	0.520	0.858	52.0
GIL4	32	22	0.688	0.500	0.839	50.0
PAN1	34	23	0.676	0.495	0.826	49.5
LBR1	38	25	0.658	0.486	0.804	48.7
BER1	48	30	0.625	0.474	0.760	47.4
EBO3	41	26	0.634	0.469	0.779	47.0
BEE2	82	47	0.573	0.459	0.682	46.0
SFD1	33	21	0.636	0.451	0.796	45.2
WBO3	32	20	0.625	0.437	0.789	43.7
BMK3	24	15	0.625	0.406	0.812	40.6
DRE1	62	32	0.516	0.386	0.645	38.6
SLA2	41	22	0.537	0.374	0.693	37.5
DKR3	35	19	0.543	0.366	0.712	36.7
RAT2	33	18	0.545	0.364	0.719	36.4
CMF1	34	18	0.529	0.351	0.702	35.2
BMK2	32	17	0.531	0.347	0.709	34.8
DRE2	59	27	0.458	0.327	0.592	32.8
CTM1	67	30	0.448	0.326	0.574	32.6
TRK1	34	17	0.500	0.324	0.676	32.5
RAT1	31	15	0.484	0.302	0.669	30.2
WMS3	83	33	0.398	0.292	0.511	29.2
WMS3	83	33	0.398	0.292	0.511	29.2
RIN2	32	15	0.469	0.291	0.653	29.1
LBE1	88	34	0.386	0.284	0.496	28.5
CRN1	33	15	0.455	0.281	0.636	28.1
CCW1	32	14	0.438	0.264	0.623	26.4
WMS2	44	18	0.409	0.263	0.568	26.4
FOR2	33	12	0.364	0.204	0.549	20.4
NFD1	46	15	0.326	0.195	0.480	19.6
ELM2	59	18	0.305	0.192	0.439	19.2
SFD2	45	14	0.311	0.182	0.466	18.2
MAR2	33	11	0.333	0.180	0.518	18.0
BER2	14	6	0.429	0.177	0.711	17.7
CCE1	33	10	0.303	0.156	0.487	15.6
EAN1	30	9	0.300	0.147	0.494	14.8
RIN3	33	9	0.273	0.133	0.455	13.3
WBO1	44	10	0.227	0.115	0.378	11.5

Appendix B

Table B1: A List of the Logistic Regression Parameters for Each Watershed Reach

Watershed Reach	Intercept β_0	Slope β_1	exp(Int) e^{β_0}	exp(Slope) e^{β_1}
BAR1	-0.044	0.136	0.957	1.146
BAR2	0.588	0.102	1.801	1.107
BAR3	1.480	0.110	4.391	1.116
BAR4	-0.118	0.242	0.888	1.274
BAR5	0.284	0.193	1.329	1.212
BAR6	0.282	0.181	1.325	1.199
BEE1	-0.752	0.340	0.472	1.405
BEE2	-1.668	0.212	0.189	1.236
BEE3	-6.507	3.326	0.001	27.835
BER1	-0.400	0.106	0.670	1.112
BER2	-1.537	0.156	0.215	1.169
BER3	-0.314	0.185	0.730	1.203
BLU1	3.963	-0.045	52.603	0.956
BLU2	1.914	0.038	6.778	1.039
BLU3	1.319	0.036	3.741	1.037
BMK1	4.834	-0.102	125.772	0.903
BMK2	-2.047	0.371	0.129	1.449
BMK3	0.368	0.012	1.445	1.012
BOG1	-0.101	0.124	0.904	1.132
BOG2	2.138	0.279	8.481	1.322
BOG3	1.304	-0.018	3.682	0.983
BRW1	-0.351	0.457	0.704	1.580
BUL1	26.566	0.000	3.45E+11	1.000
BUL2	4.002	-0.071	54.683	0.931
BUL3	25.566	0.000	1.27E+11	1.000
BUL4	24.566	0.000	4.67E+10	1.000
BUL5	25.566	0.000	1.27E+11	1.000
CAR1	25.566	0.000	1.27E+11	1.000
CAR2	0.474	0.093	1.606	1.097
CCE1	-0.533	-0.045	0.587	0.956
CCW1	-1.215	0.152	0.297	1.164
CCW2	1.366	0.058	3.921	1.060
CMF1	-1.145	0.191	0.318	1.211
CRN1	-2.675	0.360	0.069	1.433
CTM1	-0.845	0.107	0.430	1.113
DKR1	1.654	-0.062	5.230	0.940
DKR3	-0.750	0.164	0.472	1.178
DRE1	-1.120	0.197	0.326	1.217
DRE2	-0.691	0.081	0.501	1.085
DRN1	3.678	-0.025	39.564	0.975

DRN2	0.622	0.218	1.863	1.244
EAN1	-1.635	-0.003	0.195	0.997
EAN2	0.929	0.089	2.532	1.093
EBO1	0.611	0.183	1.842	1.201
EBO2	0.773	0.133	2.167	1.143
EBO3	-0.544	0.150	0.581	1.161
ELM1	-4.159	0.265	0.016	1.303
ELM2	-1.389	0.103	0.249	1.109
FOR1	-22.566	NA	0.000	N/A
FOR2	-1.095	0.090	0.334	1.094
FOR3	-0.332	0.249	0.718	1.283
FOR4	1.790	0.080	5.991	1.083
GIL1	26.566	0.000	3.45E+11	1.000
GIL2	25.566	0.000	1.27E+11	1.000
GIL3	25.566	0.000	1.27E+11	1.000
GIL4	0.165	0.102	1.179	1.108
GIL5	25.566	0.000	1.27E+11	1.000
GIL6	25.566	0.000	1.27E+11	1.000
HRP1	0.692	0.103	1.998	1.108
HRS1	1.338	0.183	3.811	1.201
HRS2	1.414	0.207	4.113	1.230
JOH1	-0.215	0.119	0.806	1.126
LBA1	1.166	0.144	3.208	1.155
LBA2	1.061	0.089	2.890	1.093
LBA3	0.827	0.054	2.287	1.055
LBE1	-2.182	0.178	0.113	1.195
LBR1	0.259	0.042	1.295	1.043
LBR2	-0.686	0.166	0.504	1.180
LKA	0.664	0.094	1.943	1.099
LKC1	0.665	0.184	1.944	1.202
LKC2	1.519	0.105	4.569	1.110
LKC3	25.566	0.000	1.27E+11	1.000
LWA1	26.566	0.000	3.45E+11	1.000
LWA2	11.052	-0.712	63042.533	0.491
LWA3	25.566	0.000	1.27E+11	1.000
LWA4	2.886	-0.094	17.924	0.910
MAR1	-1.468	1.389	0.230	4.012
MAR2	-1.853	0.168	0.157	1.183
NFD1	-1.057	0.050	0.348	1.051
ONI1	25.566	0.000	1.27E+11	1.000
ONI2	25.566	0.000	1.27E+11	1.000
ONI3	25.566	0.000	1.27E+11	1.000
ONI4	26.566	0.000	3.45E+11	1.000
ONI4a	3.450	-0.203	31.493	0.816

ONI5	3.912	-0.048	49.990	0.953
ONI6	0.526	0.204	1.692	1.226
PAN1	-1.101	0.304	0.333	1.355
RAT1	-0.157	0.009	0.855	1.009
RAT2	0.119	0.006	1.126	1.006
RDR1	0.284	0.166	1.328	1.180
RIN1	-7.153	4.469	0.001	87.257
RIN2	-0.221	0.014	0.802	1.014
RIN3	-1.856	0.126	0.156	1.135
SBG1	1.821	-0.015	6.177	0.985
SBG2	-0.594	0.210	0.552	1.234
SFD1	0.311	0.036	1.364	1.037
SFD2	-1.187	0.058	0.305	1.059
SHL1	26.561	0.000	3.43E+11	1.000
SHL2	1.797	0.177	6.032	1.194
SHL3	1.527	0.068	4.603	1.071
SHL4	-0.164	0.257	0.848	1.293
SLA1	-1.522	0.427	0.218	1.533
SLA2	-1.508	0.184	0.221	1.202
SLA3	-0.945	0.207	0.389	1.230
TAN1	1.170	0.009	3.221	1.009
TAN2	1.836	-0.044	6.269	0.957
TAN3	1.309	0.217	3.704	1.242
TRK1	-1.618	0.245	0.198	1.277
TYN1	-0.743	0.150	0.476	1.162
TYS1	2.820	0.025	16.771	1.025
WBL1	-78.003	26.601	0.000	3.57E+11
WBL2	1.511	0.089	4.533	1.093
WBO1	-1.980	0.056	0.138	1.058
WBO2	1.117	0.010	3.056	1.010
WBO3	0.080	0.069	1.083	1.071
WLN1	0.940	0.273	2.559	1.314
WLN2	2.443	0.047	11.507	1.048
WLN3	2.203	0.123	9.056	1.131
WLN4	2.789	-0.114	16.266	0.892
WLN5	25.566	0.000	1.27E+11	1.000
WLR1	26.566	0.000	3.45E+11	1.000
WLR2	25.566	0.000	1.27E+11	1.000
WLR3	1.571	0.056	4.812	1.058
WMS1	2.729	0.104	15.315	1.110
WMS2	-1.804	0.206	0.165	1.228
WMS3	-2.655	0.250	0.070	1.284