Appendix G

Hydrologic Conditions Technical Information

DRAFT Memorandum

TO: JERED CHANEY, SENIOR GEOLOGIST, WEBER, HAYES & ASSOCIATES

FROM: GARY CONLEY, CHIEF SCIENTIST, 2NDNATURE

SUBJECT: HYDROLOGIC MODELING RESULTS FOR THE UC SANTA CRUZ CAMPUS

DATE: SEPTEMBER 21, 2020

2NDNATURE is pleased to provide draft results of a hydrologic analysis to estimate runoff production on the UC Santa Cruz campus. These outputs provide an update to previous analyses and incorporate the most current spatial data sets available, including recent impervious cover changes. These runoff estimates rely on the best hydrologic understanding available, well proven modeling methods, and will be useful to inform runoff mitigation planning, regulatory compliance tracking, environmental impacts assessment, and water budget accounting on the campus.

1. CONCEPTUAL MODELING OVERVIEW

Since all environmental models are simplifications of much more complex systems, an important initial step is to identify the compromises that will be required, and the intended use of model results should ultimately guide model selection and the necessary degree of model complexity (Leavesley et al. 2002). These choices are often driven by resource availability and the purpose of the model. The most salient question is: *What do we need to use the model to do?* The answer to this question can dictate much of what gets left in and what gets left out of the model, and there are costs on both sides of that proposition. The problem is often framed as a trade-off between the degree of model complexity and the data required to support that complexity to obtain outputs with a reasonable degree of certainty. As structural complexity increases, the framework uncertainty decreases, since more of the system detail is represented. However, complex structures require higher order parameterizations, which rely on more data to specify and verify the model, so the additional complexity tends to produce greater uncertainty associated with the underlying data. A key modeling task is to identify the best balance these two sources of uncertainty for the specific modeling purpose. If we adopt a more complex model (e.g, continuous simulation at fine-scale spatial resolution), we are challenged with gathering enough real world monitoring data to supply all needed model inputs, or left wondering whether assumptions about model inputs leads to false conclusions. Thus, we seek to achieve just the level of model complexity needed to reach the point of minimum overall uncertainty resulting from the combination of model framework uncertainty and data uncertainty.

The least complex model that reliably meets the application at the relevant scale is often the best alternative (Chandler 1994, Rauch et al. 2002, Dotto et al. 2012) and model selection often boils down to choice between a greater degree of granularity across space or detail of process representation in time. Attempting to do both is computationally expensive, resource intensive, and provides more detail than required. While detailed process representation used in continuous simulation models may improve performance over short time steps, it comes at the expense of greater structural complexity (Snowling and Kramer 2001), without necessarily increasing the usefulness of outputs (Lindenschmidt 2006). Since stormwater impact mitigation problems invariably have an important spatial component and are typically less concerned with short-term outcomes, modeling approaches that employ parsimonious process-representation in favor of greater spatial granularity make intuitive sense. The 2NDNATURE hydrologic modeling approaches reflect these concepts in order to provide robust outputs that align with the data widely available for model parameterization and scales of information required by end users of the model outputs.

2. Study Area

The study area is defined by a set of watersheds and sub-basins on the UC Santa Cruz campus. Drainages were mapped in 1988 by Johnson (1988) and later digitized and modified by UCSC staff. The maps indicate surface drainage, subsurface flow paths, and areas contributing to groundwater aquifers. Karst terrain throughout the campus creates a complex hydrography that includes several sink holes, cavernous voids, and spring flows. As part of this study, 2NDNATURE reconciled sub-basin scale discrepancies between the map of Johnson (1988) and the digital data. The resulting watersheds and sub-basins shown in Figure 1 were the spatial framework used for the estimates in this study.

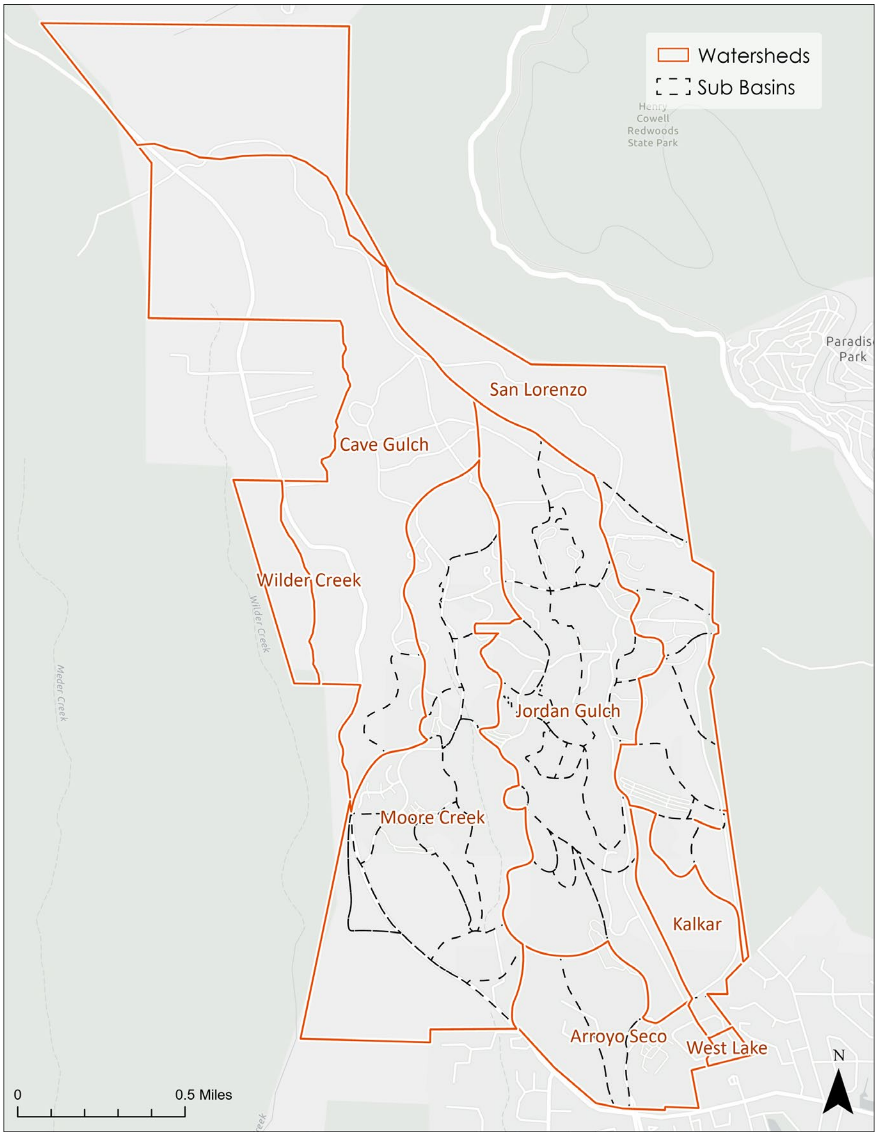

Figure 1. Study area drainages and sub-basins for the UC Santa Cruz campus

3. The swTELR model

3.1 Model Structure

Typically, stormwater runoff is modeled using 1 of 2 approaches: using discrete storm events, or continuous simulation. Event-based approaches are programmatically simple but were originally designed to simulate runoff for a single storm event size. With the Stormwater Tool to Estimate Load Reductions (swTELR), we employ a hybrid event-based approach that combines a set of events drawn from a long-term precipitation distribution to bracket the range of rainfall and runoff responses probabilistically (as opposed to explicitly with continuous simulation). The efficiency of this method allows a distributed spatial approach where runoff, loading and BMP reduction calculations are discretized on a 30-meter grid so that site-specific runoff generation and pollutant loading characteristics specific to the BMP drainages are explicitly represented. The model has shown strong correspondence with continuous simulation models and with monitoring data at scales ranging from neighborhood-scale drainages (Beck et al, 2017) to small urban catchments (Conley et al. *in review*).

3.2 RAINFALL CALCULATIONS

Stormwater TELR calculates various 24-hr precipitation depths and the average annual number of days with measurable precipitation to represent the overall distribution and total average annual depths. We calculated, d, the average number of rain days per water year when daily rainfall exceeds 0.25 cm, and P(x), various 24-hr event frequency estimates, where P is the 24-hr rainfall depth for the x^{th} percentile event. On a water-year basis, we selected 24-hr event rainfall frequencies to approximate the 24-hr event cumulative distribution function, such that these events can be summed to obtain long-term average 24-hr runoff volumes for days when it rains:

$$\int_0^{100} P(x)\,dx \approx \frac{1}{2}\sum_{k=1}^{N}\left(x_{k+1}-x_k\right)*\left(P\left(x_{k+1}\right)+P\left(x_k\right)\right) \quad \text{(EQ1)}$$

where *x* is a number between 0 and 100, and k is number in the sequence of total, N, percentile events used to estimate the integral. With this formulation, long-term average annual rainfall depth, P_{365}, is the product of the integrated 24-hr rainfall depth and the number of rain days per year, d:

$$P_{365} = d * \int P(x)\,dx \quad \text{(EQ2)}$$

This approach to characterizing the long-term precipitation distributions was compared with several other approaches in Beck et al. (2017). Runoff and decentralized BMP reductions are calculated using the individual percentile rainfall events that correspond with common water quality permit requirements and structural BMP design criteria (85^{th} and 95^{th} percentile storm events), which also include the median and the lower quartile.

3.3 RAINFALL-RUNOFF TRANSFORMATION

For a given storm magnitude, the runoff generation module defines the fraction of flow that infiltrates over pervious surfaces and the fraction of overland runoff that is eventually discharged to the receiving waters. Stormwater TELR relies on the Soil Conservation Service (SCS) curve number (*CN*) method and the approach detailed in Technical Release 55 (TR-55) to estimate runoff from small urban catchments (USDA 1986). The SCS runoff equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{EQ3}$$

where *Q* is the runoff depth, *P* is the 24-hr rainfall depth, *S* is the potential maximum retention after runoff begins, and I_a is the initial abstraction depth, which incorporates all losses before runoff begins, including water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Runoff does not begin until the initial abstraction has been met. I_a is variable across the landscape but is highly correlated to the curve number. The initial abstraction is 20% of the storage,

$$I_a = 0.2S$$

(EQ4)

and

$$S_{0.20} = \frac{1000}{CN} - 10 \tag{EQ5}$$

More recent data suggest that 0.20**S* might be too high and that 0.05**S* is more appropriate (Woodward et al., 2003, Lim et al., 2006, Shi et al., 2009) especially for hydrologic soil groups C and D (Jiang 2001). If 5%, rather than 20%, is used, *S* must also be modified. The relationship between $S_{0.05}$ and $S_{0.20}$ obtained from model fitting results is (Lim et al., 2006, Hawkins et al., 2002)

$$S_{0.05} = 1.33 * S_{0.20}^{\ 1.15} \tag{EQ6}$$

We used the adjusted initial abstraction ratio (equation 6) and by substituting equation 4, modified for 5% of storage, into equation 3, we obtain

$$Q = \frac{(P - 0.05S_{0.05})^2}{P + 0.95S_{0.05}} \tag{EQ7}$$

Thus, the model is parameterized by specifying the curve number, which ranges from 30 to 98, with lower numbers indicating low potential runoff and higher numbers indicate increasing runoff potential. The major factors that determine SCS curve numbers are the soil type, the land use (specifically, the percent impervious of the land use), the hydrologic condition and soil infiltration capability. To simply account for variations in soil permeability and infiltration, the NRCS has classified soils into 4 hydrologic soil groups (HSGs). A curve number for a given land use with impervious area can be estimated by the following (USDA 1986):

$$CN = CN_p + \frac{P_{imp}}{100}\left(98 - CN_p\right) \quad \text{(EQ8)}$$

where *CN* is the runoff curve number for the entire land use, CN_p is the pervious runoff curve number and P_{imp} is the percent imperviousness. The pervious curve numbers used are those defined for open space in poor condition (grass cover < 50%) (USDA, 1986), since urban soils are often disturbed or compacted, and are listed in Table 1. Estimates of direct runoff from curve numbers implicitly incorporate evapotranspiritive losses to the atmosphere, which is parameterized by the land cover type or impervious coverage fraction.

Table 1. Urban pervious curve numbers used in swTELR (USDA, 1986)

Soil Type	A	B	C	D
Starting Curve Number	68	79	86	89

3.4 MODEL INPUTS

Raster-based rainfall estimates from the PRISM Climate Group (2004) at Oregon State University are used to describe the distribution of 24-hour event depths to drive runoff generation. A script written in R (R core team, 2020), using functions in the *raster* package (Hijmans and Etten, 2012), is used to acquire daily rainfall raster layers for the years 1981-2016 for the study area and perform the series of processing steps outlined in Section 2.3. The 35-year daily sequence (12,775 raster layers, 800-m^2 cells), are used to create a raster coverage of rainfall percentile values and average annual days of rain for each grid cell. Soils data from NRCS is used to specify soil types throughout MS4 boundaries, used in their rasterized form, downscaled to 30-m pixels. The NRCS SSURGO database is used as the primary data source, and the STATSGO2 database (which provides coarser resolution) is used to fill in spatial gaps in coverage that occur in the SSURGO data. Impervious cover is specified using the most recent data from the National Land Cover Dataset which is provided at 30-meter grid cell resolution (NLCD, 2016).

4. RUNOFF ESTIMATES

Runoff estimates generated using the methods described in the previous sections are summarized for each of the campus watersheds in Table 2. Rainfall depths vary across the campus per the PRISM data, with watersheds occupying the higher reaches such as Cave Gulch and Wilder Creek showing somewhat higher annual rainfall totals. Average annual runoff ratios generally correspond to those areas of the campus with higher impervious cover and less inflatable soils. Also calculated in Table 2 is the estimated annual runoff from each watershed corresponding to all rainfall events up to the 85th

percentile rainfall event, which aligns with NPDES permit design requirements for post-construction requirements or low impact development implementation.

Table 2. Runoff modeling outputs for UC Santa Cruz campus drainages

Watershed	Area (ac)	Annual Rainfall (in)	Average Annual Runoff (in/yr)	Average Annual Runoff (ac-ft/yr)	Average annual Runoff Ratio (%)	Annual runoff up to the 85th percentile event (in/yr)
Arroyo Seco	123.4	37.7	10.2	107.4	27%	6.5
Cave Gulch	466.4	45.3	8.1	296.3	18%	4.4
Jordan Gulch	387.7	39.7	8.2	268.5	21%	5.0
Kalkar	61.5	39.7	9.7	30.3	24%	3.4
Moore Creek	421.4	43.9	10.5	339.2	24%	5.9
San Lorenzo	518.9	40.7	7	289.1	17%	3.9
West Lake (High Street)	5.9	39.7	16	7.7	40%	10.0
Wilder Creek	44.8	45.3	7.3	28.4	16%	4.4

Estimated runoff from the swTELR model are shown in Figure 2, with spatial patterns of runoff throughout the campus reflecting the various spatial factors contributing to runoff productions, largely driven by the proportion of impervious cover. Runoff estimates at the grid-cell scale (30m) showed maximum volumes of approximately 0.6 ac-ft/yr in the most densely developed areas of the campus. These patterns represent direct runoff after accounting infiltration and evapotranspiration, but do not take into account losses associated losses to groundwater via large subsurface flow pathways characteristic of karst terrains. Accounting for these losses will provide an estimate of the partitioning of runoff that results ultimately results in channel flow and that which may be lost to deep percolation.

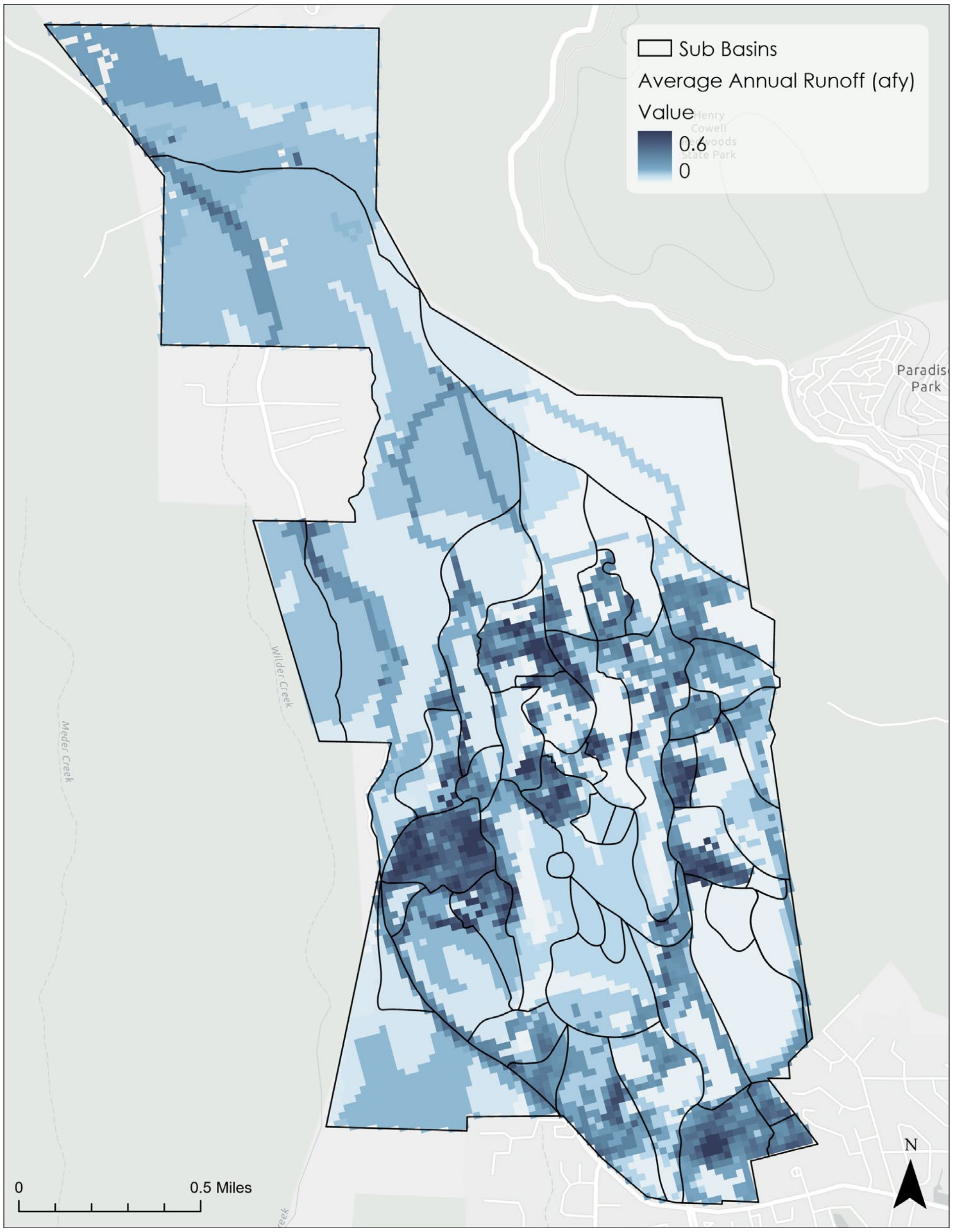

Figure 2. Runoff estimates for the UC Santa Cruz campus

Runoff ratios for the modeled sub-basins are shown in Figure 3 with most sub-basins showing from 20-30% of rainfall transformed into runoff after evapotransparitive losses. West Lake showed the highest runoff ratio of approximately 40%.

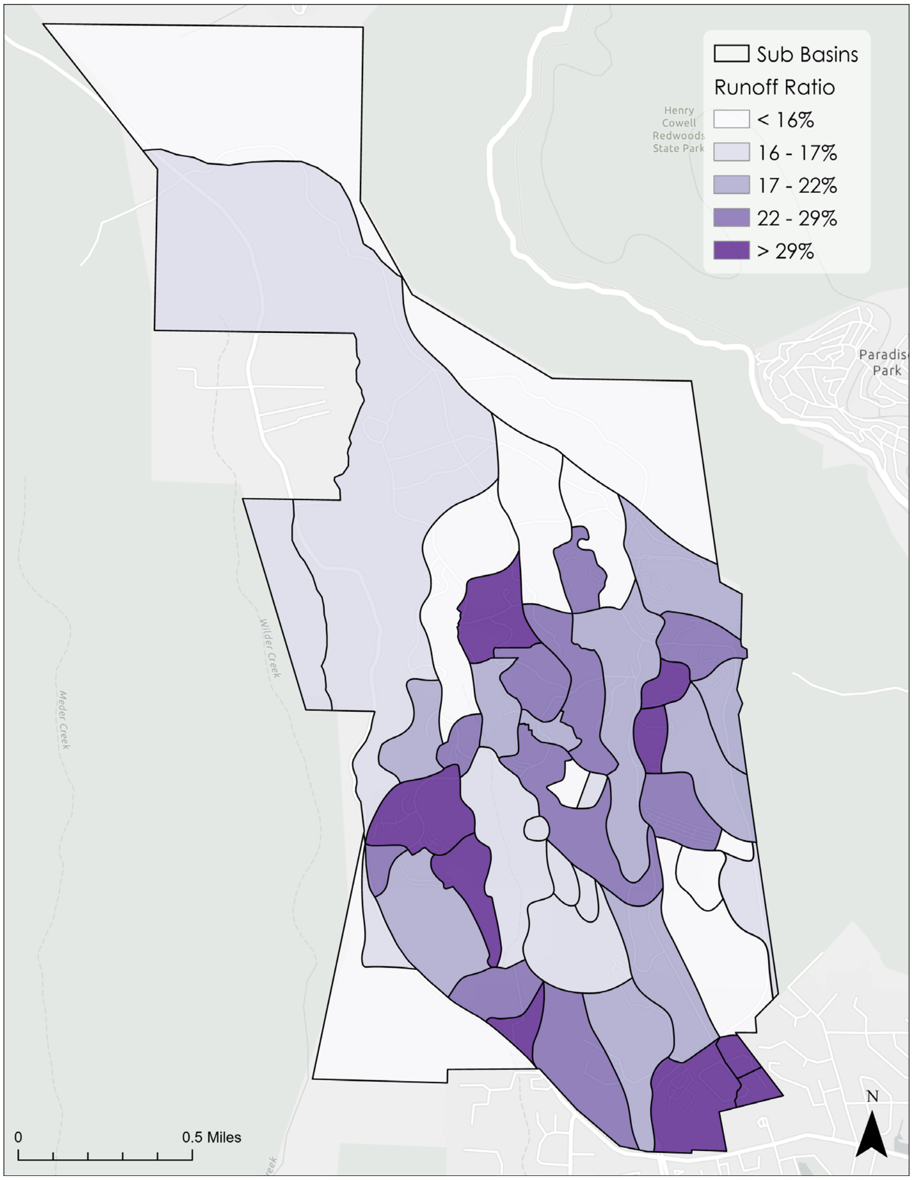

Figure 3. Sub-basin runoff ratios for the UC Santa Cruz campus

5. Conclusions

This memo communicates results of a runoff modeling analysis driven by a the spatially granular swTELR model which relies probabilistic representation of rainfall events to estimate annual runoff. Raster-based calculations provide estimates on a 30-m grid, preserving unique combinations of drainage factors that drive runoff production, hydrologic storage, and infiltration. These estimates are intended to inform planning and support environmental impact assessment for the campus and as such represent long-term average runoff given the range of rainfall conditions that are likely to occur in the coming decades. Like all model outputs, the predictions shown are subject to various sources of uncertainty that can reduce the accuracy and precision of the outputs. Not the least of these sources of error is the model input data, which does not always reflect factors such as very recent development that may have altered land use and impervious cover. Areas of complex hydrography like the UC Santa Cruz campus with abundant karst terrains present unique challenges that are also likely to contribute some ambiguity to outputs. While these sources of modeling uncertainty should always be considered, these outputs rely on the best spatial data currently available and are more than adequate for planning-level runoff estimates, assessing the relative impacts throughout the campus, and as a baseline from which to measure future changes.

References

Beck, N.G., Conley, G., Kanner, L., Mathias, M., (2017). An urban runoff model designed to inform stormwater management decisions. Journal of environmental management, 193, pp.257-269.

Chandler, R. (1994). Estimating annual urban nonpoint pollutant loads. Journal of Management in Engineering 10(6): 50-59.

Dotto, C.B.S., M. Kleidorfer, A. Deletic, W. Rauch, and D.T. McCarthy, 2014. Impacts of measured data uncertainty on urban stormwater models. Journal of Hydrology 508: 28-42. DOI:10.1016/j.jhydrol.2013.10.025

Hawkins, R.H., R. Jiang, D.E. Woodward, A.T. Hjelmfelt, and J.A Van Mullem, 2002. Runoff Curve Number Method: Examination of the Initial Abstraction Ratio. In: Proceedings of the Second Federal Interagency Hydrologic Modeling Conference, Las Vegas, Nevada. U.S. Geological Survey, Lakewood, Colorado. CD-ROM.

Jiang, R. 2001. Investigation of runoff curve number initial abstraction ratio. University of Arizona Master's Thesis. Available at http://arizona.openrepository.com/arizona/handle/10150/191301. Accessed in September 2015.

Leavesley, G.H., S.L. Markstrom, P.J. Restrepo, R.J. Viger, 2002. A modular approach to addressing model design, scale and parameter estimation issues in distributed hydrologic modeling. Hydrological Processes 16, 173-187

Lindenschmidt, K.E., 2006. The effect of complexity on parameter sensitivity and model uncertainty in river water quality modeling. Ecological Modeling 190, 72-86.

Lim, K. J., B. A. Engel, S. Muthukrishnan, and J. Harbor, 2006. Effects of initial abstraction and urbanization estimated runoff using CN technology. Journal of the American Water Resources Association 42: 629–643. DOI:10.1111/j.1752-1688.2006.tb04481.x

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 Feb 2004.

National Land Cover Database (NLCD) 2016. Urban Imperviousness, updated 2016. https://www.mrlc.gov/

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Rauch, W., J.-L. Bertrand-Krajewski, P. Krebs, O. Mark, W. Schilling, M. Schütze, and P.A. Vanrolleghem, 2002. Deterministic modeling of integrated urban drainage systems. Water Science & Technology 45(3): 81-94.

Shi, Z.H., Chen, L.D., Fang, N.F., Qin, D.F., Cai, C.F. (2009). Research on the SCS-CN initial abstraction ratio using rainfall-runoff event analysis in the Three Gorges Area, China. Catena 77 (1), 1e7. http://dx.doi.org/10.1029/2004WR003191.

Snowling, S.D., J.R. Kramer, 2001. Evaluating modeling uncertainty for model selection. Ecological Modeling 138, 17-30.

USDA-SCS (U.S. Department of Agriculture-Soil Conservation Service), 1986. Urban hydrology for small watersheds. Technical release 55, NTIS PB87-101580, 2nd edn. USDA SCS, Springfield, Virginia.

Woodward, D.E., R.H. Hawkins, R. Jiang, A.T. Hjelmfelt, Jr., J.A. Van Mullem, and Q.D. Quan, 2003. Runoff Curve Number Method: Examination of the Initial Abstraction Ratio. In Conference Proceeding Paper, World Water and Environmental Resources Congress 2003: pp.1-10.

TABLE G1-1
SPRING AND STREAM FLOW RATES AND GROUNDWATER ELEVATIONS

DATE	BAY STREET SPRING *gpm*	WEST LAKE WEIR *gpm*	MESSIAH LUTHERAN SPRING *gpm*	KALKAR SPRING QUARRY *gpm*	HIGH-LONGVIEW SPRING *gpm*	WAGNER GROVE SEEP *gpm*	HARVEY WEST SEEP *gpm*	POGONIP CREEK SYSTEM *gpm*	POGONIP SPRING #1 *gpm*	POGONIP SPRING #2 *gpm*	UPPER CAVE GULCH *gpm*	LOWER CAVE GULCH *gpm*	WILDER CREEK SPRING *gpm*	MOORE CREEK SPRING *gpm*	□MW-1A *(ft, MSL)*	□MW-1B *(ft, MSL)*	WSW 1 *(ft, MSL)*
09/11/84	95	4	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
09/25/84	110	4	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
10/02/84	120	1	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
10/09/84	95	1	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
10/18/84	135	**	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
10/25/84	105	35	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
11/09/84	170	65	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
11/21/84	190	190	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
11/26/84	175	190	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
12/02/84	165	**	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
12/10/84	170	190	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
01/23/85	140	**	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/11/85	141	140	**	190	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/28/85	142	140	**	150	**	**	**	**	**	**	**	**	500	Not Obtained	**	**	**
04/08/85	143	80	**	140	**	**	**	**	**	**	**	**	500	Not Obtained	**	**	**
06/18/85	144	40	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
07/24/85	145	20	**	50	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
11/11/85	146	40	**	20	**	**	**	**	**	**	**	**	100	Not Obtained	**	**	**
04/13/87	147	50	**	120	**	**	**	**	**	**	**	**	500	Not Obtained	**	**	**
08/12/87	120	25	**	60	**	**	**	**	**	**	**	**	300	Not Obtained	**	**	**
10/12/87	130	16	**	70	**	**	**	**	**	**	**	**	200	Not Obtained	**	**	**
12/18/87	165	130	**	90	**	**	**	**	**	**	**	**	500	Not Obtained	**	**	**
01/26/88	180	130	**	240	**	**	**	**	**	**	**	**	800	Not Obtained	**	**	**
03/09/88	155	50	**	170	**	**	**	**	**	**	**	**	400	Not Obtained	**	**	**
06/15/88	130	13	**	85	**	**	**	**	**	**	**	**	270	Not Obtained	**	**	**
09/26/88	120	1	**	50	**	**	**	**	**	**	**	**	60	Not Obtained	**	**	**
11/13/88	118	**	**	20	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
12/06/88	116	**	**	71	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
12/30/88	155	**	**	45	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
01/07/89	147.7	**	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
01/11/89	137	**	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
01/13/89	**	**	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	319.92	**	321.02
01/17/89	**	**	58.4	**	40.6	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
01/18/89	134	53.3	**	**	38.7	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
01/29/89	**	65.3	**	**	**	**	**	161.6	**	**	**	**	161.6	Not Obtained	**	**	**
02/02/89	**	**	51.4	**	43.4	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/03/89	146.2	62.8	**	89.8	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/11/89	133.9	58.4	61.4	98.7	54.1	**	**	170.5	**	**	**	**	193	Not Obtained	**	**	**
02/12/89	132.4	58.3	59.1	103.2	42.9	**	**	193	**	**	**	**	197.5	Not Obtained	**	**	**
02/13/89	132.7	53.3	57.6	98.7	52.1	**	**	197.5	**	**	**	**	**	Not Obtained	319.6	**	319.86
02/14/89	129.6	43.1	56.2	103.2	46.3	**	**	197.5	**	**	**	**	193	Not Obtained	**	**	**

TABLE G1-1
SPRING AND STREAM FLOW RATES AND GROUNDWATER ELEVATIONS

DATE	BAY STREET SPRING *gpm*	WEST LAKE WEIR *gpm*	MESSIAH LUTHERAN SPRING *gpm*	KALKAR SPRING QUARRY *gpm*	HIGH-LONGVIEW SPRING *gpm*	WAGNER GROVE SEEP *gpm*	HARVEY WEST SEEP *gpm*	POGONIP CREEK SYSTEM *gpm*	POGONIP SPRING #1 *gpm*	POGONIP SPRING #2 *gpm*	UPPER CAVE GULCH *gpm*	LOWER CAVE GULCH *gpm*	WILDER CREEK SPRING *gpm*	MOORE CREEK SPRING *gpm*	□MW-1A *(ft, MSL)*	□MW-1B *(ft, MSL)*	WSW 1 *(ft, MSL)*
02/15/89	129.9	44.6	56.5	112.2	47.4	**	**	193	**	**	**	**	179.5	Not Obtained	**	**	**
02/16/89	128.3	47.8	54.8	103.2	39.1	**	**	188.5	**	**	**	**	197.5	Not Obtained	**	**	**
02/17/89	133.7	49.9	56.1	94.2	34.5	**	**	193	**	**	**	**	166.1	Not Obtained	**	**	**
02/18/89	140.9	58.1	79.4	125.7	48.5	**	**	233.4	**	**	**	**	152.6	Not Obtained	**	**	**
02/19/89	131.4	57.9	58.4	107.7	24.4	**	**	224.4	**	**	**	**	179.5	Not Obtained	**	**	**
02/20/89	134	43.6	55.8	98.7	12.6	**	**	206.5	**	**	**	**	215.4	Not Obtained	**	**	**
02/21/89	132	48.2	52.3	103.2	17.3	**	**	**	**	**	**	**	**	Not Obtained	318.88	**	317.2
02/22/89	128	43.6	53.1	103.2	9.2	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/23/89	127.3	30.1	53	98.7	20.8	**	**	193	**	**	**	**	139.1	Not Obtained	**	**	**
02/24/89	131	43.3	53.3	94.2	13.2	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/25/89	131.7	36.4	53.1	107.7	11.9	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/26/89	127.1	37.5	53.7	107.7	37	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/27/89	**	**	**	**	18.6	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/28/89	**	**	**	**	30.1	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
03/04/89	130.1	43.6	67.9	125.7	**	**	**	224.4	**	**	**	**	857	Not Obtained	**	**	**
03/11/89	147.3	175.9	108.2	161.6	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
03/12/89	**	**	**	**	70.4	**	**	**	**	**	**	**	1207	Not Obtained	**	**	**
04/03/89	131.4	61.3	61	4 162	52	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
04/04/89	**	**	**	**	**	**	**	184	**	**	**	**	485	Not Obtained	**	**	**
04/24/89	**	**	**	**	**	**	**	180	**	**	**	**	**	Not Obtained	**	**	**
05/01/89	121.7	**	**	135	**	**	**	**	**	**	**	**	171	Not Obtained	**	**	**
05/02/89	**	30.6	52.4	**	43.5	**	**	211	**	**	**	**	**	Not Obtained	**	**	**
05/06/89	**	**	**	**	**	**	**	**	7.8	21.6	**	**	**	Not Obtained	**	**	**
06/04/89	**	**	**	**	**	**	**	**	**	**	**	**	103	Not Obtained	**	**	**
06/05/89	121.2	22.5	22.5	4 148	17.5	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
06/06/89	**	**	**	**	**	**	**	189	**	**	**	**	**	Not Obtained	**	**	**
06/07/89	**	**	**	**	**	**	**	**	5	17.7	**	**	**	Not Obtained	**	**	**
06/23/89	**	**	45.6	81	**	**	**	**	**	**	**	**	108	Not Obtained	**	**	**
06/26/89	**	**	**	**	**	**	**	**	3.5	9.4	**	**	**	Not Obtained	**	**	**
07/10/89	115.7	5.8	**	85	17.7	**	**	162	**	**	**	**	81	Not Obtained	**	**	**
07/11/89	**	**	44.7	**	**	**	**	**	2.8	16.8	**	**	**	Not Obtained	**	**	**
07/20/89	**	**	**	**	**	**	**	**	3	6	**	**	**	Not Obtained	**	**	**
08/11/89	114.5	**	**	85	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
08/12/89	**	**	**	**	**	**	**	**	3	**	**	**	**	Not Obtained	**	**	**
08/18/89	118.8	4.7	48	81	32.1	**	**	175	**	**	**	**	63	Not Obtained	**	**	**
10/04/89	123.6	1.1	43.7	67.5	1.9	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
11/01/89	143.4	27.8	57.7	94.5	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
11/22/89	139.8	35.8	51.4	53.5	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
01/03/90	138.3	42.9	50.4	33.3	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**

TABLE G1-1
SPRING AND STREAM FLOW RATES AND GROUNDWATER ELEVATIONS

DATE	BAY STREET SPRING *gpm*	WEST LAKE WEIR *gpm*	MESSIAH LUTHERAN SPRING *gpm*	KALKAR SPRING QUARRY *gpm*	HIGH-LONGVIEW SPRING *gpm*	WAGNER GROVE SEEP *gpm*	HARVEY WEST SEEP *gpm*	POGONIP CREEK SYSTEM *gpm*	POGONIP SPRING #1 *gpm*	POGONIP SPRING #2 *gpm*	UPPER CAVE GULCH *gpm*	LOWER CAVE GULCH *gpm*	WILDER CREEK SPRING *gpm*	MOORE CREEK SPRING *gpm*	¤MW-1A *(ft, MSL)*	¤MW-1B *(ft, MSL)*	WSW 1 *(ft, MSL)*
01/29/90	140.4	48	52.1	42.5	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/23/90	147.1	43.3	58.7	48.8	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
04/04/90	135.4	17.8	47	31.7	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
04/20/90	130.7	14.2	39.2	26.9	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
05/12/90	131.7	**	26	17.3	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
05/20/90	**	4.3	**	**	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
06/02/90	121	40.9	52.7	15.5	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
06/08/90	124	21.1	39.5	23.6	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
07/05/90	130.7	0	36	**	**	**	**	**	**	**	**	**	**	Not Obtained	312.07	367.83	**
07/20/90	129	0	33	5	**	**	**	**	**	**	**	**	**	Not Obtained	312.07	367.52	**
08/12/90	124	0	38	0	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
09/05/90	109.1	0	3.6	0	0.75	0	0	137	13.5	2.22	**	5	40.4	Not Obtained	311.04	367.29	**
09/28/90	103.8	0	29.2	0	**	**	**	113.1	**	**	**	**	28.7	Not Obtained	310.51	367.27	**
10/15/90	104.4	0	21.1	0	0.33	0	1.5	155	7.4	1.85	0.1	3	21.1	Not Obtained	310.08	367.18	**
10/29/90	101.1	0	27.6	0	**	**	**	132.6	**	**	**	**	19.3	Not Obtained	309.72	367.1	**
11/14/90	99.9	0	25.2	0	0.3	0	1	136.9	10.8	1.5	1.5	4.5	19.3	Not Obtained	309.35	366.98	322.2
11/28/90	107.9	0	28.63	0	**	**	**	147.8	**	**	**	**	14.6	Not Obtained	309.1	366.96	323.175
12/12/90	111.9	0	32.2	0	0.33	0	2	152.8	10.9	1.7	1.5	3.8	14.2	Not Obtained	308.8	366.84	323.099
01/03/91	127.5	0	33	0	**	**	**	157.5	**	**	**	**	20.7	Not Obtained	308.56	366.69	321.994
01/17/91	110.5	0	34.8	0	**	0	1	154.9	10	1.23	2	1.9	25.6	Not Obtained	308.34	366.56	322.175
01/31/91	113.1	0	31	0	**	**	**	167.7	**	**	**	**	24.6	Not Obtained	308.13	366.43	321.251
02/07/91	120.2	**	**	0	**	**	**	**	**	**	**	**	**	Not Obtained	**	**	**
02/14/91	118.9	0	39.9	0	0.33	0	1.5	162.3	10.5	1.25	3	3.8	34.7	Not Obtained	308.45	366.24	321.251
02/26/91	114.6	0	34.4	0	**	**	**	149.9	**	**	**	**	23.7	Not Obtained	308.17	366.17	321.251
03/12/91	132.7	56.4	61.1	0	0.5	0	18.8	160.2	23.5	3.53	22.6	12.6	192	Not Obtained	310.74	366.12	323.792
03/30/91	165	151.1	82.7	87.3	15	**	**	183.4	**	**	**	**	945.3	Not Obtained	315.15	367.05	328.643
04/24/91	133.7	76.2	54.5	87.8	15	0	4.5	157.5	21.4	4	23.5	7.9	190.7	Not Obtained	316.13	367.33	328.874
05/08/91	127	53	47.5	70.8	18.5	**	**	147	**	**	**	**	124.3	Not Obtained	315.79	367.55	328.412
05/24/91	123.5	28.3	33.9	54.9	19.5	0	1.5	148.6	15.3	3.2	13.1	9	95.7	Not Obtained	315.19	367.38	327.95
06/05/91	121.2	30.7	44	45.2	**	**	**	154.2	**	**	**	**	86.1	Not Obtained	314.78	367.35	327.257
06/20/91	112.5	14.65	39.75	33	12.4	0	1	148.5	9.8	3.64	5.15	7.7	88.8	Not Obtained	314.27	367.45	327.257
07/05/91	118.1	8.96	39.1	38.6	**	**	**	156.8	**	**	**	**	93.1	Not Obtained	313.775	367.55	325.54
07/23/91	112.3	8.96	38.86	21.87	1.6	0	1	166.6	15.4	2.69	2.73	4.1	62.14	Not Obtained	313.29	367.575	326.102
08/12/91	112.1	0	34.77	32.69	**	**	**	114.5	**	**	**	**	58.3	Not Obtained	312.72	367.58	325.178
08/23/91	107.4	0	36.97	5.44	0	0	1	150.6	11.4	2	1.367	6.717	39.7	Not Obtained	312.41	367.6	325.409
09/05/91	105.5	0	33.79	2.3	**	**	**	150.8	**	**	**	**	33.52	Not Obtained	311.835	367.58	325.178
09/19/91	110.3	0	31.53	3.1	0	0	0.75	151	7.232	1.75	1	4.941	41.77	Not Obtained	311.76	367.55	324.023
10/09/91	107.3	0	32.34	0	0	**	**	131.2	**	**	**	**	26.14	Not Obtained	311.29	367.5	324.254
10/25/91	109.7	0	36.76	0	0	0	0.75	167.7	10.4	1.4	1	5.167	21.26	Not Obtained	310.875	367.35	323.792

TABLE G1-1
SPRING AND STREAM FLOW RATES AND GROUNDWATER ELEVATIONS

DATE	BAY STREET SPRING *gpm*	WEST LAKE WEIR *gpm*	MESSIAH LUTHERAN SPRING *gpm*	KALKAR SPRING QUARRY *gpm*	HIGH-LONGVIEW SPRING *gpm*	WAGNER GROVE SEEP *gpm*	HARVEY WEST SEEP *gpm*	POGONIP CREEK SYSTEM *gpm*	POGONIP SPRING #1 *gpm*	POGONIP SPRING #2 *gpm*	UPPER CAVE GULCH *gpm*	LOWER CAVE GULCH *gpm*	WILDER CREEK SPRING *gpm*	MOORE CREEK SPRING *gpm*	□MW-1A *(ft, MSL)*	□MW-1B *(ft, MSL)*	WSW 1 *(ft, MSL)*
11/08/91	109.3	0	37.25	0	0	**	**	150	**	**	**	**	30.03	Not Obtained	310.83	367.25	323.792
11/25/91	105.2	5.908	40.63	0	0	0	0.75	155.7	10.33	1.752	4.363	6.312	44.54	Not Obtained	310.725	367.129	323.561
12/17/91	98.43	0	38	0	0	0	0.75	158.1	6.664	1.24	1	6.725	49.85	Not Obtained	310.725	366.965	323.33
01/03/92	136	109.4	60.89	8.096	3.747	0	7.106	156.5	22.05	2.1	14.03	7.26	166.1	Not Obtained	311.56	366.86	324.023
01/14/92	144.8	93.86	62.88	21.38	11.82	**	**	152.9	**	**	**	**	187.8	Not Obtained	313.27	366.835	326.102
01/30/92	125.9	30.7	50.17	33.71	12.96	0	2	145.4	8.177	1.3	4.926	4.993	88.29	Not Obtained	313.14	336.835	326.102
02/13/92	192.3	255.5	129	223.3	52.94	298.3	< 150	408.5	**	**	**	>1000	3040.62	Not Obtained	315.8	366.835	326.102
02/27/92	166.3	221.4	88.64	218.2	22	0	157.9	164.7	54.6	25.04	47.86	13.46	967.76	Not Obtained	323.55	368.12	335.111
04/28/92	118.3	86.82	60.7	214.8	116	**	**	160.7	**	**	**	**	218.7	Not Obtained	325.055	370.015	339.038
05/15/92	120.6	65.26	57.13	346.5	Discontinued	0	2	139.5	13.8	5.566	18.84	5.086	178.5	Not Obtained	323.97	370.08	339.038
06/03/92	86.86	59.58	55.63	190.1	Discontinued	0	2	131.1	12.6	5.976	**	4.843	136.1	Not Obtained	322.68	370.09	337.652
07/09/92	81.42	48.4	46.85	172.5	Discontinued	0	1	153.4	12.75	4.352	3.548	2.992	107.4	Not Obtained	320.4	369.81	334.187
07/25/92	78.27	40.35	7.765	121.1	Discontinued	**	**	146.8	**	**	**	5.731	77.23	Not Obtained	319.31	369.7	334.649
08/12/92	74.88	27.09	44.75	108.1	Discontinued	0	1	135.8	10.15	3.794	3	2.618	**	Not Obtained	318.4	369.56	333.956
08/28/92	81.59	33.82	47.45	83.2	Discontinued	**	**	143.4	**	**	**	**	**	Not Obtained	317.45	369.47	333.263
09/15/92	74.23	21.96	42.84	93.33	Discontinued	0	1	142.1	8.571	2.694	1	**	**	Not Obtained	316.7	369.37	333.032
09/28/92	72	32.56	40.53	81.76	Discontinued	**	**	138.5	2.9	2.73	1	**	**	Not Obtained	316.11	369.22	331.877
11/10/92	73.09	19.81	38.6	66.85	Discontinued	0	1	138.7	7.621	1.992	1	6.25	42.38	Not Obtained	314.23	368.63	329.78
12/10/92	103.8	109.4	70.18	63.09	Discontinued	4	4	152.7	11.44	14.6	89.34	6.904	214.4	Not Obtained	314.04	368.43	329.798
01/26/93	158.8	350	118	516.5	Discontinued	5.73	172.2	257.4	86.78	64.61	175.6	182.7	1409	Not Obtained	329.23	370.25	344.582
04/18/94	86.48	76.2	49.77	245.8	Discontinued	0	3	175.4	20.36	7.945	16.36	10.64	158.5	Not Obtained	321.39	321.12	369.12
03/31/95	140	302.8	82.26	652.6	Discontinued	0	15	205	62.3	37.97	172	128.4	1092	5	335.22	372.98	327.95
10/04/95	87.44	97.9	49.74	145.7	Discontinued	0	2	150.7	20	6.25	15	5.891	132.3	10	323.71	370.29	316.4
03/30/96	136.6	287	77.72	488.34	Discontinued	0	10	257.1	81.62	27.18	104.09	207.79	1001.39	15	338.98	372.83	334.19
10/27/96	82.94	16.71	43.78	123.42	Discontinued	0	< 5	80.27	11.55	5.47	5	3.43	137.92	< 10	323.29	369.55	318.71
03/19/97	96	175.72	57.2	318.3	Discontinued	0	< 5	349.91	52.15	12.38	21.24	33.1	982.65	20	319.85	373.06	330.26
10/08/97	89.9	23.07	30	111.82	Discontinued	0	< 5	155.58	24	1.23	0	5.88	156.74	5	*>324.1	369.72	322.18
04/13/98	116	287.19	73.33	1370.4	Discontinued	7.8	13.8	646.87	96.67	49.8	379.27	247.78	1526.48	29.2	344.9	373.9	314.1
10/06/98	112	95.65	43.33	103.93	Discontinued	0	< 5	307.44	47.33	4.5	40	15-30	251.52	< 5	327.2	370.23	317.6
03/30/99	128.75	221.43	51.25	317.9	Discontinued	2.5	31	378.86	132.5	36	117.85	161.59	1269.73		335.95	371.92	**
08/20/99	77	40.35	44	259.18	Discontinued	**	< 5	*** 719.58	52	7	0	52.47	351.54	2.42	327.43	370.35	330.26
01/07/00	**	**	**	**	Discontinued	**	**	*** 294.87	**	**	**	**	**		**	**	**
03/22/00	107.75	309.46	63.66	1110.56	Discontinued	0	25	559.5	62	12.29	0	161.33	1044.58	7.5	340.5	372.68	338.35
09/25/00	73.59	21.96	41.62	135.58	Discontinued	0	< 5	310.12	19.86	3.52	0	15	466.68	1.58	324.27	370.02	*****
03/22/01	89.96	143.82	48	196.07	Discontinued	0	10	161.29	36.6	8.8	0	15	721	0.6	327.62	369.77	330.26
11/09/01	61.12	16.71	28	65.52	Discontinued	0	< 5	182.51	25.2	2.88	0	12	104.42	0.5	321.28	365.52	311.78
06/04/02	122.12	11.96	45.5	197.9	Discontinued	0	< 5	309.4	47.85	3.6	0	21.78	252.27	0.53	325	360	316.4
10/10/02	106.42	21.96	45.46	65.42	Discontinued	0	1	92.11	10.3	3.96	0	7.5	202.7	1.82	320.57	368.95	*****
03/19/03	117.58	114.13	61.59	260	Discontinued	0	< 5	233.38	37.44	6.96	0	175	565	3.23	328.46	359.68	*****

TABLE G1-1
SPRING AND STREAM FLOW RATES AND GROUNDWATER ELEVATIONS

DATE	BAY STREET SPRING *gpm*	WEST LAKE WEIR *gpm*	MESSIAH LUTHERAN SPRING *gpm*	KALKAR SPRING QUARRY *gpm*	HIGH-LONGVIEW SPRING *gpm*	WAGNER GROVE SEEP *gpm*	HARVEY WEST SEEP *gpm*	POGONIP CREEK SYSTEM *gpm*	POGONIP SPRING #1 *gpm*	POGONIP SPRING #2 *gpm*	UPPER CAVE GULCH *gpm*	LOWER CAVE GULCH *gpm*	WILDER CREEK SPRING *gpm*	MOORE CREEK SPRING *gpm*	□MW-1A *(ft, MSL)*	□MW-1B *(ft, MSL)*	WSW 1 *(ft, MSL)*
09/30/03	76.7	4.23	38.28	78.45	Discontinued	0	< 5	242.58	16.7	3.72	0	10.05	124.9	2	319.84	368.81	*****
03/19/04	134.87	114.13	62.77	185.11	Discontinued	0	< 3	249.33	23.48	6.67	0	117.6	753.98	3	328.07	359.15	*****
09/22/04	96.3	1	38.24	77.5	Discontinued	0	< 1	174.19	12.16	5.36	0	10	111.36	1	319.30	369.06	*****
03/18/05	156.47	186.81	86.14	702.51	Discontinued	0	6	307.83	46.62	38.24	0	277.91	887.44	1.26	320.13	369.54	*****
09/28/05	104.83	24.77	55.87	164.76	Discontinued	0	< 1	247.85	20.21	5.8	0	24.56	219.14	1	325.00	371.18	*****
03/21/06	230.89	406.79	135.35	971.49	Discontinued	115.72	181.57	574.70	153.76	55.6	1239.94	1357.45	4944.03	18.60	340.01	373.08	*****
09/18/06	108.01	114.13	71.76	160.63	Discontinued	0	< 2	480.71	76.31	15.67	0	29.40	220.41	2.00	328.79	370.77	*****
03/21/07	97.26	86.62	56.50	156.43	Discontinued	0	1	398.67	33.09	22.09	0	21.93	436.52	1	327.00	370.40	*****
09/18/07	60.35	1.07	31.92	127.35	Discontinued	0	< 1	274.70	10	4	0	5	95.95	< 2	321.96	369.18	*****
11/09/07	58.07	20.88	21.3	--	Discontinued	--	--	--	--	--	--	--	--	--	--	--	--
11/10/07	64	16.71	21.7	--	Discontinued	--	--	--	--	--	--	--	--	--	--	--	--
11/11/07	76.5	40.35	30	--	Discontinued	--	--	--	--	--	--	--	--	--	--	--	--
11/12/07	74.8	27.68	30	--	Discontinued	--	--	--	--	--	--	--	--	--	--	--	--
11/13/07	74	86.82	24	--	Discontinued	--	--	--	--	--	--	--	--	--	--	--	--
03/21/08	97.4	133.67	37	547.5	Discontinued	0	< 10	267.78	15	10	0	15	375.8	< 5	332.58	370.68	331.81
09/19/08	81	4.23	22.8	178.79	Discontinued	0	< 5	165.64	5	4	0	10	151.36	< 2	321.19	369.46	321.52
03/23/09	97.5	133.67	32	110.74	Discontinued	Discontinued	Discontinued	230.42	87.21	12	Discontinued	Discontinued	361.97	< 3	326.11	370.36	325.32
09/19/09	66	1.49	17	105.36	Discontinued	Discontinued	Discontinued	170.92	4	4	Discontinued	Discontinued	59.17	< 2	319.45	369.74	318.74
03/24/10	90.6	203.88	30	523	Discontinued	Discontinued	Discontinued	319.26	17.5	16.5	Discontinued	Discontinued	889	< 5	333.91	370.83	333.14
09/17/10	88.57	16.71	21	49.22	Discontinued	Discontinued	Discontinued	252.97	22.5	4.5	Discontinued	Discontinued	133.59	< 2	323.61	367.58	322.8
03/17/11	205	276.9	53.3	884.05	Discontinued	Discontinued	Discontinued	368.24	233.53	30	Discontinued	Discontinued	1433.02	< 10	334.49	371.53	335.13
09/16/11	70	40.35	30	151.68	Discontinued	Discontinued	Discontinued	181.31	20	8.2	Discontinued	Discontinued	198.89	< 0.5	327.83	371.34	327.29
03/16/12	95	123.77	60	207.42	Discontinued	Discontinued	Discontinued	390.70	22.5	40	Discontinued	Discontinued	2616.95	< 25	322.40	370.15	321.52
09/21/12	43	1.49	15	106.1	Discontinued	Discontinued	Discontinued	232.55	12.5	4.9	Discontinued	Discontinued	151.1	0	320.15	369.54	319.31
03/15/13	79	54.52	30	222.38	Discontinued	Discontinued	Discontinued	234.31	17.5	6.3	Discontinued	Discontinued	228.36	< 1	323.23	369.67	322.49
09/20/13	67	0	23	19.37	Discontinued	Discontinued	Discontinued	231.24	10	3.3	Discontinued	Discontinued	7.73	0	317.13	368.94	316.38
03/14/14	36	95.65	56	158	Discontinued	Discontinued	Discontinued	131.63	152	19.45	Discontinued	Discontinued	270.12	< 2	316.84	369.25	316.2
09/19/14	21	0	15	10	Discontinued	Discontinued	Discontinued	123.47	29.9	3	Discontinued	Discontinued	44.9	0	313.49	367.68	312.13
03/13/15	33	0	31.2	41.78	Discontinued	Discontinued	Discontinued	212.90	53.9	7.5	Discontinued	Discontinued	879.6	0	321.64	370.12	320.38
09/25/15	23	0	12	10	Discontinued	Discontinued	Discontinued	238.61	7	2.3	Discontinued	Discontinued	67.3	0	314.49	368.56	313.03
03/18/16	95	245.57	155.6	424.67	Discontinued	Discontinued	Discontinued	306.27	329	48.72	Discontinued	Discontinued	1871.65	5	333.03	371.80	331.83
09/23/16	36	4.23	55.5	72.8	Discontinued	Discontinued	Discontinued	223.93	58.3	4.41	Discontinued	Discontinued	260	0	321.61	370.40	320.07
03/10/17	95	451.14	236.63	1865.51	Discontinued	Discontinued	Discontinued	414.47	761.5	58.96	Discontinued	Discontinued	1991.62	8	356.23	376.44	354.79
09/22/17	36	27.68	81	155.43	Discontinued	Discontinued	Discontinued	244.30	203	10.6	Discontinued	Discontinued	294.82	0	327.81	371.48	326.6
03/19/18	36	55.13	75	124.54	Discontinued	Discontinued	Discontinued	270.55	201	12	Discontinued	Discontinued	610.89	5	322.09	370.38	321.00
08/24/18	33	12.09	19.5	94.15	Discontinued	Discontinued	Discontinued	244.30	79.3	5	Discontinued	Discontinued	256.76	1	321.89	370.10	320.66
09/20/18	26	4.27	57.3	75.64	Discontinued	Discontinued	Discontinued	286.11	44.9	4	Discontinued	Discontinued	109.4	0	320.87	370.02	319.62
10/18/18	26	0	12.7	64.28	Discontinued	Discontinued	Discontinued	189.39	56.8	4.9	Discontinued	Discontinued	200.5	0	319.92	369.90	318.65
11/20/18	21	0	14.3	63.42	Discontinued	Discontinued	Discontinued	227.67	46.4	3.8	Discontinued	Discontinued	273.8	0	318.77	369.75	317.55
12/21/18	36	63	84	77.88	Discontinued	Discontinued	Discontinued	256.26	160	8	Discontinued	Discontinued	703.1	2	319.32	369.97	317.97
01/19/19	77	189	71	135.91	Discontinued	Discontinued	Discontinued	554.42	113	45	Discontinued	Discontinued	3,077	3	322.80	370.72	321.52
02/22/19	83	300	127	885.61	Discontinued	Discontinued	Discontinued	153.80	266	60	Discontinued	Discontinued	1,761	5	337.83	--	336.59
03/15/19	72	313	107	888.25	Discontinued	Discontinued	Discontinued	352.31	149	61	Discontinued	Discontinued	2,104	5	340.22	--	338.96
04/19/19	56	125	77	431.95	Discontinued	Discontinued	Discontinued	214.71	80.44	21.5	Discontinued	Discontinued	516	3	335.85	373.24	334.65
05/18/19	52	71	94	313.15	Discontinued	Discontinued	Discontinued	265.09	127.49	19	Discontinued	Discontinued	606	3	332.50	372.64	331.29
06/21/19	48	63	43	288.07	Discontinued	Discontinued	Discontinued	295.57	175	19	Discontinued	Discontinued	196	2	330.95	372.21	329.8
07/22/19	36	48	25	256.59	Discontinued	Discontinued	Discontinued	325.22	215	15	Discontinued	Discontinued	500	2	329.24	371.90	328.1

Notes:

* = Solinst groundwater level meter not long enough to reach groundwater.

** = Not measured this monitoring period, either because flow rate was not being verified or there was no flow -dry.

*** = Flow rate incorrect (calculation/field measurement error).

**** = Corrected flow rate measurement due to error in previous round of measurement or calculation.

***** = Air line used to measure pressure head is clogged or broken. Unable to record PSI measurement, therefore no groundwater level obtained, or elevation reported.

□ = Data logging transducers were installed in wells MW-1A and MW-1B on 8/23/07 and record water levels in these wells every 12 hours. Groundwater elevation reported in this table on 9/18/07 and beginning 8/24/19 to present was interpreted from transducer data.

Data from 11/9 - 11/13 was collected during a 72-hour constant rate pump test at well WSW 1. Flow was only measured at Bay Street Spring, Messiah Lutheran Spring, and at West Lake Weir.

Top of well casing (TOC) survey was conducted by Ifland Engineers at WSW-1, MW-1A and MW-1B on 12/5/07. TOC elevations are 416.41, 424.84, and 418.69 feet relative to Mean Sea Level at wells WSW 1, MW-1A, and MW-1B, respectively.

gpm = gallons per minute. (ft, MSL) = Feet, above reference of mean sea level.

Table G1-2
UCSC Hydrogeologic Balance

Drainage Basin Areas, Rainfall Runoff and Recharge, Spring Discharge, and Water Balance

Watershed/Drainage Area Name/Type	Wilder Creek (30% runoff to subsurface-subarea W1)[5]	Cave Gulch (100% runoff to subsurface-subarea C1)[5]	Cave Gulch (30% runoff to subsurface-subarea C2)[5]	Moore Creek (100% runoff to subsurface-subarea M1, M2.2)[5]	Moore Creek (60% runoff to subsurface-subarea M2.1)[5]	Moore Creek (100% runoff to surface-subarea M3)[5]	Western Tributary Moore Creek (100% runoff to subsurface-subarea T1)[5]	Western Tributary Moore Creek (100% runoff to surface-subarea T2)	Jordan Gulch (100% runoff to subsurface-subarea J1)[5]	Jordan Gulch (100% runoff to surface-subarea J2)	Jordan Gulch (60% runoff to subsurface-subarea J3)[5]	Arroyo Seco (100% runoff to subsurface-subarea A2)[5]	Arroyo Seco (100% runoff to surface-subarea A2)	High Street (100% runoff to surface- subarea H1)		Kalkar Quarry (100% runoff to surface-subarea K1)[5]	Kalkar Quarry (100% runoff to surface-subarea K2)	Kalkar Quarry (100% runoff to subsurface-subarea K2)	San Lorenzo River (100% runoff to subsurface-subarea S1)[5]	San Lorenzo River (100% runoff to surface-subarea S1)[5]	San Lorenzo River (100% runoff to surface-subareas S2-S6)[6]				Total Karst Drainage Area (Potentially Influenced)
Off-Campus Karst Recharge Drainage Area (acres)[1]	548	0	124	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0				672
On-Campus Karst Recharge Drainage Area (acres)[1]	48.8	25.4	440	116.3	130	8.6	11.9	100.2	364.1	12.5	66	22.5	98.1	5.9		5.9	46.6	9.2	51.2	42.2	78				1683.4
Rainfall (in/yr)[2]	45.3	45.3	45.3	43.7	44	40	45.3	45	39.8	39.8	39.8	37.7	37.7	39.7		39.7	39.7	39.7	39.7	39.7	41.8				41.4
Existing Undeveloped Area (%)	100%	96%	100%	88%	94%	86%	98%	99%	91%	91%	91%	86%	86%	69%		70%	98%	98%	94%	94%	95%				91%
Existing Impervious Area (%)[3]	0%	4%	0%	12%	6%	14%	2%	1%	9%	9%	9%	14%	14%	31%		30%	2%	2%	6%	6%	5%				9%
Annual Runoff % (2020 TELR matrix)[4]	16%	19%	16%	22%	24%	34%	16%	15%	21%	21%	21%	27%	27%	40%		37%	12%	12%	16%	16%	18%				22%
Total Runoff (in/yr)	7.2	8.6	7.2	9.6	10.6	13.6	7.2	6.8	8.4	8.4	8.4	10.2	10.2	15.9		10.7	4.8	4.8	6.4	6.4	7.5				8.6
Total Runoff (acre-ft/yr)	360.5	18.2	340.7	93.2	114.4	9.7	7.2	56.4	253.6	8.7	46.0	19.1	83.2	7.8		5.3	18.5	3.7	27.1	22.3	48.9				1544.4
Infiltration Recharge (in/yr)	38.1	36.7	38.1	34.1	33.4	26.4	38.1	38.3	31.4	31.4	31.4	27.5	27.5	23.8		29.0	34.9	34.9	33.3	33.3	34.3				32.8
Captured Runoff Recharge (in/yr)[6]	2.2	8.6	2.2	9.6	6.3	0.0	7.2	0.0	8.4	0.0	5.0	10.2	0.0	0.0		10.7	0.0	4.8	6.4	0.0	0.0				4.1
On-Campus Runoff Recharge Only (acre-ft/yr)	**163.6**	**95.9**	**1475.0**	**423.5**	**430.9**	**18.9**	**44.9**	**319.4**	**1207.6**	**32.8**	**200.5**	**70.7**	**225.0**	**11.7**		**19.5**	**135.7**	**30.4**	**169.4**	**117.3**	**222.8**				**5415.4**
Subarea Total Recharge (acre-ft/yr)	2000.6	95.9	1890.6	423.5	430.9	18.9	44.9	319.4	1207.6	32.8	200.5	70.7	225.0	11.7		19.5	135.7	30.4	169.4	117.3	222.8				7668.1
Drainage Area Total Recharge (acre-ft/yr)	**2000.6**	**1986.5**		**873.4**			**364.3**		**1440.9**			**295.7**		**11.7**		**185.6**			**509.5**						**7668.1**
Discharge Measuring Station	Wilder Creek Spring	Upper Cave Gulch	Lower Cave Gulch	Moore Creek Spring			No Known Spring		Bay Street Spring	West Lake Outlet	No Known Spring	No Known Spring		Messiah Lutheran Spring	High-Longview Spring	Kalkar Quarry Spring			Wagnar Grove Seep		Harvey West Seep	Pogonip Creek System	Pogonip Spring #1	Pogonip Spring #2	**Total Discharge**
With surface elevation	330 ft MSL	540 ft MSL	330 ft MSL	410 ft MSL (approx.)					235 ft MSL	255 ft MSL				255 ft MSL	250 ft MSL	310 ft MSL			200 ft MSL		110 ft MSL (approx.)	150 ft MSL	435 ft MSL	500 ft MSL	
Average Discharge (gpm)[8]	450.7	46.5	63.3	4.3					110.6	66.4				50.6	23.1	161.0			7.8		13.6	221.8	58.3	13.04	1290.7
Average Discharge (acre-ft/yr)	727.4	75.0	102.1	7.0					178.4	107.2				81.6	37.2	259.8			12.5		22.0	357.9	94.1	21.0	2083.3
Watershed Spring/Stream Discharge (acre-ft/yr)	**727.4**	**177.1**		**7.0**					**285.7**					**118.8**		**259.8**			**507.5**						**2083.3**
Water Balance																									**Total Outflow**
Total Surplus Recharge (Presumed Groundwater Outflow) (acre-ft/yr)	**1273.2**	**1809.4**		**866.4**			**364.3**		**1155.2**			**295.7**		**-107.1**		**-74.2**			**1.9**						**5584.8**

Notes:

<u>Water Balance Equation:</u> Surplus Recharge (or Presumed Groundwater Outflow) = (Precipitation x Area) + Surface Inflow + Groundwater Inflow + Captured Runoff - Surface Runoff - Evapo-Transpiration - Spring Outflow

Water balance table adopted from URS Revised UCSC Water Balance (3/14/2008)

Drainage basin areas are approximately representative of extent of the underlying karst aquifer. All are on campus except for the upper off-campus Wilder Creek and Cave Gulch drainages. The San Lorenzo River subareas S7 & S8 (348 acres), although on-campus, do not contribute to karst aquifer recharge

Surface water and groundwater inflow from outside the karst recharge drainage area are presumed to be negligible, based on the topographic setting of the UCSC campus

Discharge measuring station locations are classified within approximate geographical drainage area boundaries; however, source of groundwater surface discharge may not necessarily originate within the drainage area where located.

1 Source: Johnson, "Evaluation of Drainage Conditions at UCSC Under Existing and Proposed Campus Development", Figures 3 & 4, Table 3, June 1988. Onsite drainage areas updated by UCSC 2005 Draft LRDP EIR Table 4.8.1 and Appendix D2 (Table D2-1), URS, 2005 and later digitized and modified by UC Santa Cruz staff in 2018.

2 Rainfall based on Stormwater TELR modeling calculations for various 24-hr precipitation depths and the average annual number of days with measurable precipitation to represent the overall distribution and total average annual depths. Rainfall estimates obtained from the PRISM Climate Group (2004) at Oregon State University.

3 Source: 2NDNATURE (2020) Hydrologic Modeling Results for the UC Santa Cruz Campus. September 21. Impervious cover is specified using the most recent data from the National Land Cover Dataset which is provided at 30-meter grid cell resolution (NLCD,2016)

4 Source: 2NDNATURE (2020) Hydrologic Modeling Results for the UC Santa Cruz Campus. September 21. The runoff analysis embeds an Evapotranspiration estimate.

5 Assumed percentage of runoff captured by karst sinkholes in partial subsurface drainage subareas, source: Johnson, Weber & Associates "Evaluation of Groundwater resources at UCSC Parts I & II", page 57, march 1989. URS, 2008.

6 The San Lorenzo River subareas S7 & S8 (348 acres), although on-campus, do not contribute to karst aquifer recharge but recharges the shallow sandstone/schist/granitic aquifer which outflows to the San Lorenzo River north of campus, source: Johnson, Weber & Associates "Evaluation of Groundwater Resources at UCSC part I & II", Page 57, March 1989.

7 Annual average of data collected between September 1984 through July 2019. Monitoring of High-Longview Spring, Wagner Grove Seep, Harvey West Seep and Upper / Lower Cave Gulch has been discontinued due to inaccessibility or low, unmeasurable flow. Average flow rates for these locations through the period monitored are used to estimate the hydrogeologic balance.

Memorandum

TO: JERED CHANEY, SENIOR GEOLOGIST, WEBER, HAYES & ASSOCIATES

FROM: 2NDNATURE

SUBJECT: WATER YEAR CLASSIFICATION FOR THE UC SANTA CRUZ CAMPUS

DATE: 5/26/2021

In support of the Draft Environmental Impact Report (EIR) for the UC Santa Cruz Long Range Development Plan (LRDP), 2NDNATURE is pleased to present the results of a statistical analysis of historical rainfall to characterize water year types. This analysis provides context for the results of a modeling study to estimate the impacts of groundwater pumping activities on local stream flows. The outputs of this analysis will improve the interpretation of how inter-annual rainfall variance may affect rainfall-runoff relationships and groundwater pumping impacts by providing the statistical basis to characterize the monitoring data in terms of historical wetness conditions.

STUDY AREA

The study area is defined by the UC Santa Cruz campus boundary located on the northwest edge of the City of Santa Cruz, CA (figure 1). The campus spans an area of 2,000 acres and has an elevation range of 285 to 1,195 ft.

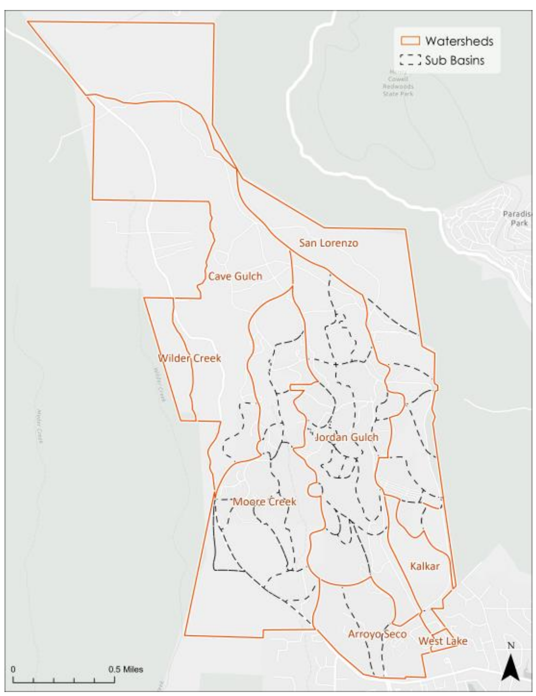

Figure 1. Study area drainages and sub-basins for the UC Santa Cruz campus

Methods & Results

A precipitation frequency analysis was conducted using 39 years of precipitation data to determine the water year precipitation thresholds that define 5 water year types (very dry, dry, normal, wet, and very wet). These data brackets a wide range of historical conditions to provide a reliable characterization of historical wetness conditions.

Data Acquisition & Processing

Precipitation data for the study area was obtained from daily rainfall raster grids from the PRISM Climate Group. PRISM datasets, widely used in climate research, are gridded spatial outputs developed from a comprehensive network of rainfall monitoring stations (Daly, 2008). These data provide a robust spatial interpolation of rainfall across the landscape from point station data, which incorporates changes in elevation, aspect, and other geographically varying factors that affect precipitation patterns. The daily rainfall raster grids (4 km resolution) for the period 1982 to 2020 were accessed and processed in the Google Earth Engine platform (Gorelick et al., 2017). PRISM grid cells along with the study area boundary are shown in Figure 2. Mean daily rainfall totals for the UCSC campus boundary were spatially weighted based on the space occupied by each grid cell within the study area, and summed by water year (October 1 – September 30) to calculate annual rainfall totals.

Water Year Designations

Annual exceedance probabilities were calculated from the 39 years of rainfall data and used to define water year type thresholds (table 1). The exceedance probability (*P*) indicates the likelihood (or percent probability) that an annual rainfall total will be equaled or exceeded in any given year and is calculated as

$$P = \frac{\mathrm{m}}{\mathrm{n} + 1}$$

where *m* represents the rank of the annual rainfall total, with 1 being the largest possible value, and *n* represents the number of events on record. Points for each year define a curve that can be used to classify water year types as shown in Figure 3. The thresholds chosen are such that the 'normal' rainfall year category bracketed the middle 30% of annual rainfalls totals, and the extreme categories (very wet and very dry) are defined by less than 10% probability of occurrence. Precipitation ranges for each water year type and the exceedance probabilities that define the lower bounds of each category are provided in Table 1. Water year type recurrence interval, calculated as $n_{total}/n_{category}$, is included to characterize the number of years within which you are likely to experience a given water year type. This approach provides a simple and clear connection between annual rainfall, probability of occurrence, and relative wetness conditions expected to occur on UCSC campus.

Table 1. Classification of water year types for UC Santa Cruz based on rainfall exceedance probability breaks

Water Year Type	Precipitation Range (in/yr)	Exceedance Probability	n	Recurrence Interval (years)
Very Dry	≤ 23.5	≥ 0.90	4	10
Dry	23.5 - 33.2	≥ 0.67	9	4
Normal	33.2 - 51.1	≥ 0.33	13	3
Wet	51.1 - 71.0	≥ 0.10	9	4
Very Wet	> 71.0	< 0.10	4	10

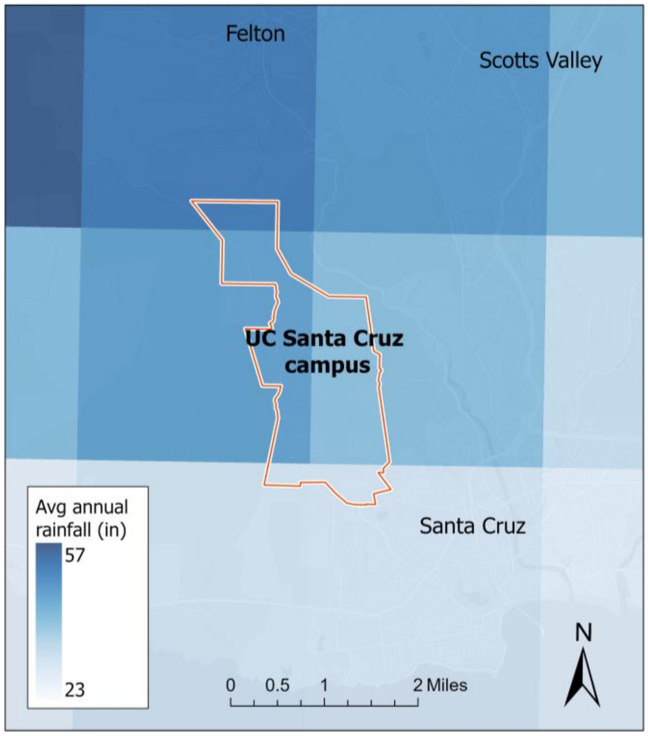

Figure 2. UC Santa Cruz study area with average annual rainfall grid extracted from PRISM

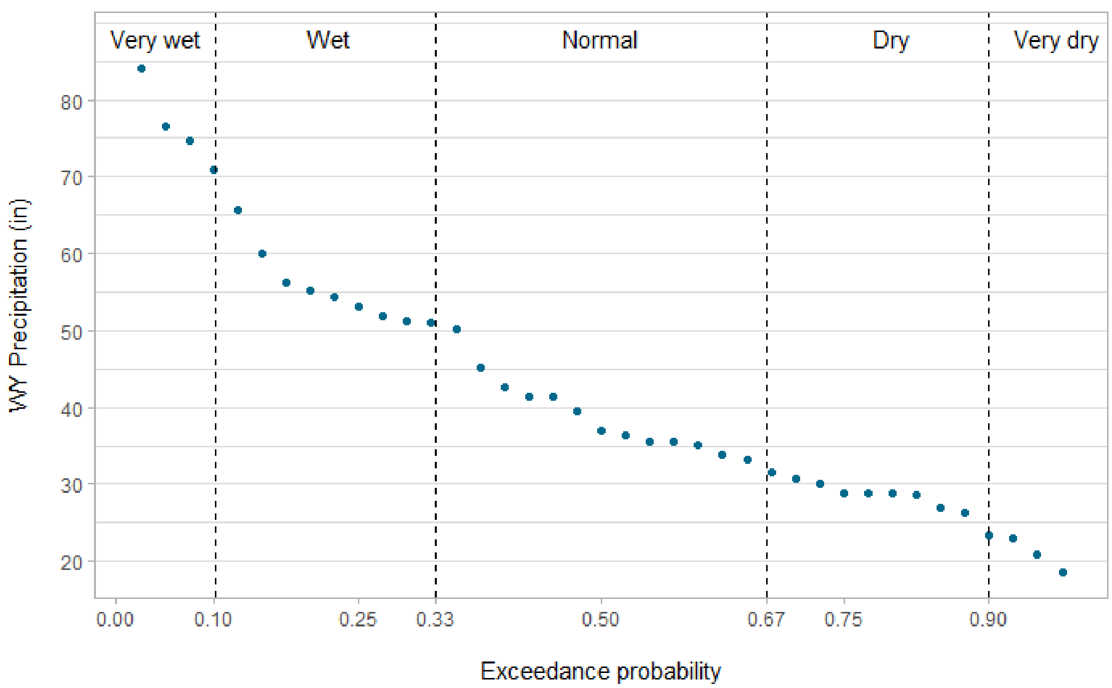

Figure 3. Water year type classification for UCSC based on probability of exceedance breaks

Rainfall Water Year Classification & Streamflow

Rainfall patterns are a primary driver of watershed streamflow conditions, and as such, rainfall-based water year type classification is expected to correspond with streamflow conditions within UCSC and in surrounding drainages (Cayan 1993). To characterize regional water supply conditions, the City of Santa Cruz uses a water year classification system with four types (very dry, dry, normal, wet) based on annual cumulative stream flow in the San Lorenzo River. We performed an analysis to verify correspondence between the rainfall-based index calculated above and the City's streamflow-based index. As shown in Figure 4, while there is some variance due to the complexities of rainfall-runoff transformation, but there is generally good agreement between the two approaches. This result is supportive that the rainfall-based classification thresholds provide meaningful context in terms of both rainfall and streamflow conditions in the watersheds within and connected to the UCSC campus.

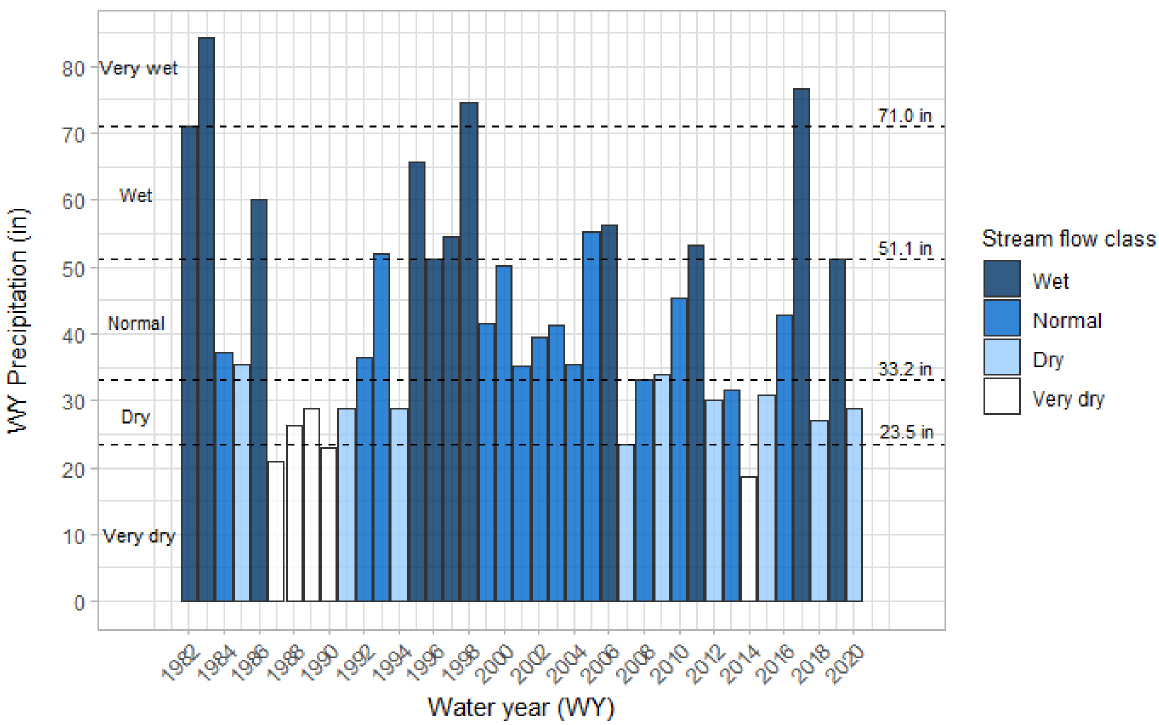

Figure 4. Comparison of rainfall-based water year types with City of Santa Cruz streamflow-based water year classification. Dashed lines represent rainfall-based water year classification from this analysis. Bar colors represent the City's streamflow-based classification approach.

REFERENCES

Cayan, D. R., Riddle, L. G., & Aguado, E. (1993). The influence of precipitation and temperature on seasonal streamflow in California. *Water Resources Research*, *29*(4), 1127-1140.

Daly, C., Halbleib, M., Smith, J.I., Gibson, W.P., Doggett, M.K., Taylor, G.H., Curtis, J., and Pasteris, P.A. (2008). Physiographically-sensitive mapping of temperature and precipitation across the conterminous United States. *International Journal of Climatology*, 28: 2031-2064

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone.

Water Department, City of Santa Cruz (2013). Revised Water Supply Outlook for 2013. https://www.cityofsantacruz.com/Home/ShowDocument?id=31327

2NDNATURE (N.D.). Napa Watershed Water Year Classification Methodology. https://www.napawatersheds.org/managed_files/Document/6838/WaterYear_Methodology.pdf