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INTRODUCTION

Streamflow duration is a major driver of biodiversity, as well as ecological functions in streams. Additionally, streamflow duration is a key factor in determining jurisdictional authority and assessing regulatory requirements under various federal, state, and local laws in the United States. However, hydrologic data to assess streamflow duration is only available at a small number of sites due to the abundance of streams and scarcity of long-term stream gauges. Consequently, watershed managers need a rapid, field-based streamflow duration assessment method (SDAM) for sites where long-term hydrologic data are unavailable.

Need for streamflow duration assessments

A 2019 proposed revision of the definition for waters of the U.S. designates perennial and intermittent tributaries as jurisdictional under the Clean Water Act (CWA), and ephemeral tributaries as not subject to CWA. Since 2006, the jurisdictional determinations under the CWA have been informed by the relative permanence of streams. Various other requirements under the CWA and other federal and state regulations are also tied to the presence of perennial or more than intermittent or more than ephemeral flow. Currently, the National Hydrography Dataset (NHD) identifies streams as perennial and intermittent across the U.S., but ephemeral streams were not originally intended to be included (Fritz et al. 2013). Additionally, NHD mapped streams are known to generally underestimate flow duration and the extent of the stream network (Fritz et al. 2013). Therefore, an efficient and accurate field assessment method of streamflow duration is needed to inform stream designations as perennial, intermittent or ephemeral across the U.S.

Ecological consequences of streamflow duration

In this pilot study, we evaluated two SDAMs developed for the western US at 36 sites representing a range of conditions in the Arid Southwest. Our goal was to compare determinations made by the SDAMs with determinations from local experts and from independent hydrological data (such as stream gauges, site photographs, or data loggers). In addition, we evaluated indicators not included in these protocols. Based on these comparisons, we made recommendations on the need for developing an SDAM for the Arid Southwest and indicators that should be evaluated for use in the region.

Streamflow duration classes

Definitions of streamflow duration classes are provided by Nadeau (2015):

- *Perennial* streams contain water continuously throughout a year during years with normal rainfall. Streamflow is sustained by groundwater and may be supplemented by snowmelt or surface runoff.
- *Intermittent* streams contain water for only part of the year during years with normal rainfall. Streamflow is sustained by groundwater and may be supplemented by snowmelt or surface runoff.
- *Ephemeral* streams contain water only in direct response to precipitation, and flows for short periods only after large storm events. Stormwater is the primary source of water, and the streambed is always above the local water table.

METHODS

Study area

The Arid Southwest is characterized by low precipitation, and the landscape is dominated by non-perennial streams (Figure 1), many of which are thought to be ephemeral. Much of the region experiences hot, dry summers, with most precipitation occurring as rain. In Mediterranean portions of coastal California, precipitation is restricted to winter months, whereas interior desert regions may experience summer monsoons (Gasith and Resh 1999, USACE 2008). The predominant vegetation is grassland or scrubland, with few forests or woodlands. The study area was divided into four major regions: Coastal California, and three desert regions in California, Arizona, and New Mexico (Figure 1).

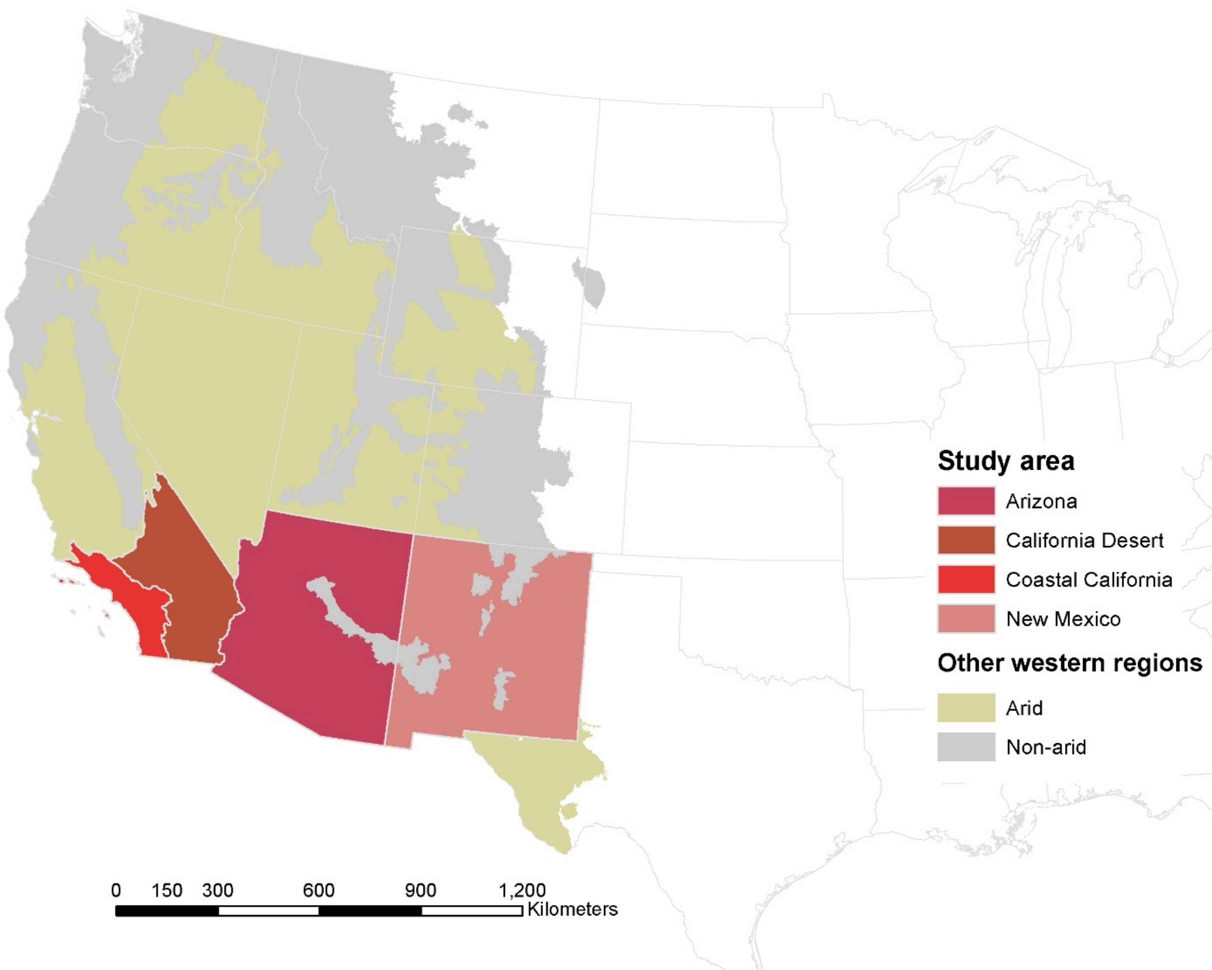

Figure 1. Map of the study area.

Site selection

Within each region, we identified candidate sites by consulting local experts and evaluating United States Geological Survey (USGS) stream gauges. Local experts were provided the definitions above and were asked to recommend appropriate sites. The length and recency of expertise was recorded for each site. In a few cases, multiple experts were consulted about the same sites.

Where available, streamflow classes were determined from independent hydrologic data, such as USGS stream gauges, HOBO data loggers, wildlife cameras, and site photos. Determinations were made as follows:

> USGS stream gauges: The most recently available daily discharge data (or gauge height, if discharge was unavailable) was downloaded from selected gauges in the region (up to 10 years, where available), and daily hydrographs were visually inspected. Streams were classified as perennial if records indicated continuous flow in most years; as intermittent if extended dry periods were evident in most years; or as ephemeral if wet periods typically lasted fewer than 10 days. Multi-year records were necessary for a perennial or ephemeral determination; records ranged from 2 to 19 years for perennial designations, 1 to 26 years for intermittent designations, and 16 to 18 years for ephemeral designations.
>
> HOBO data loggers: Water level data from HOBO data loggers were plotted and visually inspected. Streams were classified as perennial if records indicated continuous flow in most years; as intermittent if extended dry periods were evident in most years; or as ephemeral if wet periods were typically lasted fewer than a few days.
>
> Wildlife cameras: Wildlife cameras deployed by the Arizona Department of Environmental Quality. These cameras took one photo per day at noon (plus additional photos if triggered by a motion sensor). The presence or absence of water each day was noted. Streams were classified as perennial if records indicated continuous flow in most years; as intermittent if extended dry periods were evident in most years; or as ephemeral if wet periods typically lasted fewer than 10 days.
>
> Site photographs: Site photographs from other studies (Mazor et al. 2012, Mazor et al. 2014) were used to document the presence or absence of water during a site-visit. Because of the sporadic nature of this data type, these data were only used to classify streams as intermittent in cases where photos indicated the presence of surface water multiple weeks apart, as well as the absence of water in that same year. Site photographs were not used to classify streams as perennial or ephemeral.

In general, local expertise and independent hydrologic data were not both available at every site. Where both were available, we looked for consensus between hydrologic data and local expertise; sites where they disagreed were excluded from the study. Hydrologic data were unavailable at 18 of the 36 sites (2 perennial sites, 6 intermittent sites, and 10 ephemeral sites); at these sites, local expertise was the sole independent source of information on streamflow duration class.

Data collection

Site visits

Sites were visited between April and November in 2018. In coastal California, all visits occurred during the dry spring/summer season. The California and New Mexico desert regions were assessed in the spring/early summer, prior to the monsoon season. The Arizona region was visited in the fall, after summer monsoons. Some Arizona sites were assessed two weeks after heavy precipitation events; all other sites were visited several months after the most recent rain event. One site in the California desert was assessed twice in 2018 (once in April and once in August). Unless otherwise stated, data from the initial visit was used in analyses. At each site, a reach approximately 30 to 40 times the channel width (up to 200 m) was evaluated following the two protocols described below.

Pacific Northwest (PNW) SDAM

Indicators of flow duration were measured following Nadeau (2015), as described below.

Hydrologic indicators

Hydrologic indicators included visual estimates of the extent of surface water, subsurface flow, and pools at each site.

Biological indicators

Aquatic invertebrates were collected for up to 15 minutes for field-based identification; in dry streams, suitable microhabitats (e.g., remnant pools, under large cobbles, stream margins) were searched for shells, cases, exuviae, and other evidence of aquatic invertebrates. Specimens were identified to the best practical level in the field (generally family), and vouchers of every taxon encountered were retained and sent to a lab to verify identifications. The presence of taxa designated as indicators of perennial flow in Nadeau et al. (2015) were noted; a list of perennial indicator taxa is included in Appendix 1.

Plants growing within half the channel-width of the stream were noted. Hydrophytes (i.e., those with Facultative-Wet [FACW] or Obligate [OBL] status in the Arid West Regional Wetland Plant List from the US Army Corps of Engineers, Lichvar et al. 2016) were noted, regardless of prevalence or dominance. Taxa not included in Lichvar et al. (2016), such as *Populus freemontii*, were not considered to be hydrophytes. Where necessary, photo vouchers or specimens were collected to verify identifications.

Observations of fish or aquatic life stages of snakes and amphibians were noted. Mosquito-fish (*Gambusia*) were noted separately.

Geomorphic indicators

Valley slope was measured using a clinometer.

New Mexico (NM) SDAM

Indicators of flow duration were measured following NMED (2011) (Table 1). Only the first phase of this protocol was implemented (level-1). Although this protocol allows determinations to be drawn based on only a few indicators, all level-1 indicators were measured at every site. In contrast to the more objective PNW SDAM, this method requires a subjective rating of indicators, largely based on visual estimation. Following consultation with NMED staff (Kris Barrios), scoring with intermediate values was allowed.

Table 1. Indicators measured as part of the NM SDAM. Each indicator is scored based on visual observation. The total score is then used to determine streamflow duration, as described in Table 2.

Hydrologic indicators	Max score	Description
WaterInChannel	6	Evidence of flow throughout reach
HydricSoils	3	Presence of iron-oxidizing bacteria or fungi
SedimentOnPlants	1.5	Extent and consistency of sediment deposition on plants in the channel and on floodplain.
SeepsSprings	1.5	Evidence of springs or seeps discharging into the reach
Biological indicators		
Fish	3	Ease and consistency of finding fish throughout reach. Mosquito fish are included in assessments.
BMI	3	
FilamentousAlgae	3	Ease and consistency of finding benthic macroinvertebrates throughout reach. Dead algal mats are included in assessments.
DifferenceVeg	3	Extent of compositional and/or density differences in riparian vegetation vs. surrounding uplands
RootedPlants	3	Absence of upland rooted plants in the thalweg of the stream.
IronOxidizing	1.5	Presence of iron-oxidizing bacteria or fungi
Geomorphological indicators		
Sinuousity	3	Extent of stream meandering within reach.
Floodplain	3	Connectivity to floodplain/lack of confinement. Entrenchment ratio.
InChannelStructure	3	Frequency of riffle/pool sequences
SubstrateSorting	3	Evidence of substrate sorting. Differentiation between streambed substrate and surrounding uplands.

Because the NM SDAM relies heavily on subjective assessments, a few additional steps were taken to assess the potential for bias among practitioners. First, results from 2018 site visits were compared to data from earlier visits by NMED staff. In addition, data were collected by multiple independent practitioners at two sites (Tenaja Creek on 4/2/2018: R. Mazor, C. Loflen, and D. Woodward; Arroyo Seco on 7/17/2018: R. Mazor and M. Beck) to intercalibrate measurements prior to recording a final assessment.

Hydrologic indicators

Hydrologic indicators included presence and continuity of flow in the channel, presence of hydric soils, extent of sediment deposition on plants or debris in the floodplain, and presence of seeps or springs in the reach.

Biological indicators

Biological indicators included the consistency and ease of observing fish, benthic macroinvertebrates, or algae throughout the reach; distinctness of riparian vegetation from adjacent uplands; absence of upland rooted plants in the streambed; and presence of iron-oxidizing bacteria or fungi. In contrast to the PNW SDAM, *Gambusia* were not excluded when assessing fish. In dry channels, presence of dead algal mats was included when assessing extent of algae.

Geomorphic indicators

Geomorphic indicators include sinuosity, flood plain channel dimensions, extent of development of an in-channel riffle-pool sequence, and extent of substrate sorting.

Additional indicators

Two additional indicators were measured, beyond those required in NMED (2011) and Nadeau (2015). First, we noted the presence of dried algal mats in dry streambeds. Second, we noted the presence of "streamer" mosses, as described in Fritz et al. (2006). Streamer mosses are a growth form of pleurocarp mosses with distinctive, prostrate growth pattern and are considered to be indicative of longer duration flows.

Data analysis

Determining streamflow class

Streamflow class determinations were made following the protocols for each SDAM. For the PNW SDAM, we followed the decision tree in Nadeau (2015; Figure 2). For the NM SDAM, we added up the scores for all Phase 1 indicators, and interpreted the score following the table in NMED 2011 (Table 2). The NM SDAM allows for tentative determinations of intermittent and perennial stream (for which Phase 2 assessment is required); unless otherwise stated, tentative determinations were treated as final determinations (e.g., tentatively intermittent determinations were treated as intermittent).

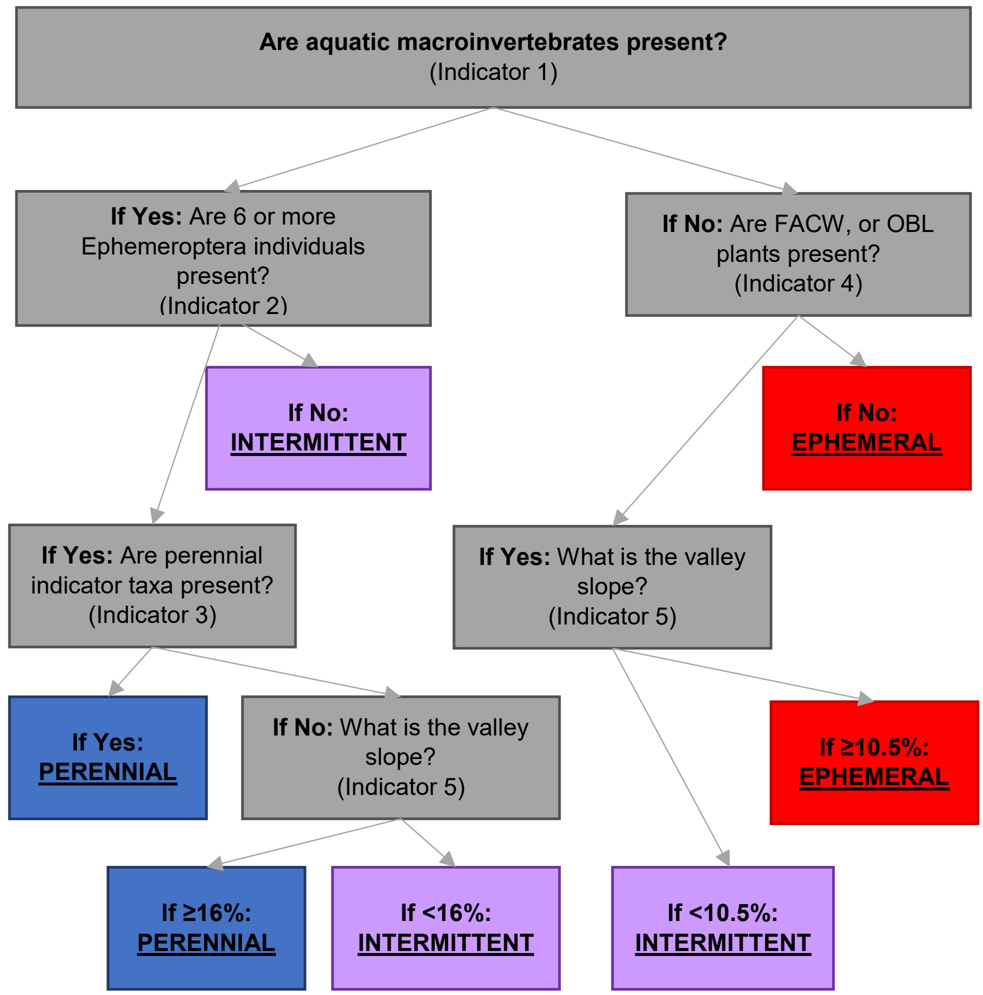

Figure 2. Decision tree to determine streamflow duration class in the Pacific Northwest. Adapted from Nadeau 2015.

Table 2. Score interpretation for the NM SDAM. Adapted from NMED 2011.

Waterbody type	Level 1 total score	Determination
Ephemeral	Less than 9.0	Stream is ephemeral
	≥ 9.0 and < 12.0	Stream is recognized as intermittent until further analysis indicates that the stream is ephemeral. *Treated as intermittent for this study.*
Intermittent	≥ 12 and ≤ 19.0 ***or*** score is lower but aquatic macroinvertebrates and/or fish are present	Stream is intermittent
	> 19.0 and ≤ 22.0	Stream is recognized as perennial until further analysis indicates that the stream is intermittent. *Treated as perennial for this study.*
Perennial	Greater than 22.0	Stream is perennial

Comparing SDAM determinations and indicators with determinations from local expertise and hydrologic data

Overall accuracy of the SDAMs as assessed as the percent of sites in the diagonal of a confusion matrix comparing SDAM determinations with determinations from local expertise or hydrologic data. Accuracy was evaluated for each region, as well as each stream-type (i.e., perennial, intermittent, and ephemeral); wet and dry intermittent streams were further evaluated as separate groups.

A Kruskall-Wallis test was used to evaluate the strength of associations between individual indicators and stream-flow duration classes. Specifically, this test was used to evaluate differences in indicator values among the three classes, as well as between perennial vs. non-perennial and ephemeral vs. non-ephemeral streams. This test was repeated on comparisons of perennial vs. wet intermittent sites and ephemeral vs. dry intermittent sites. The chi-square statistic was then used to rank indicators by discrimination ability.

Evaluation of SDAM and indicator variability

One perennial site was visited twice in 2018 (i.e., the Whitewater River, a perennial stream in the California Desert), once in April and once in August. Determinations and indicator values for the two site-visits were compared.

All sites assessed in New Mexico were used to develop or validate the NM SDAM and have been assessed by the staff of the New Mexico Environment Department with this protocol, mostly in 2008 (with other visits conducted in 2009, 2010, and 2012). Two sites (i.e., Galisteo Creek at Cerrillos and Cerro Gordo) were visited by NMED staff in multiple years. Data collected for the NM SDAM in this study were compared to data collected by NMED staff.

RESULTS

Data collection

A total of 36 sites were visited (one site visited twice) in the four study regions. Thirteen sites were ephemeral, 15 intermittent, and 8 perennial. Eight of the intermittent streams were visited during dry (or nearly dry, surface flow ≤ 1% of reach area) conditions, and 7 were visited during flowing conditions; all ephemeral streams were dry or nearly dry during site visits, and all perennial streams were flowing.

Summary of SDAM determinations

Overall, the PNW SDAM was more accurate than the NM SDAM. For example, the PNW SDAM correctly determined streamflow duration at 81% of sites vs. 67% for the NM SDAM (Table 3, Figure 3). Restricting analyses to sites with hydrologic data increased this difference (Table 3). The NM SDAM had a greater propensity for designating a site as perennial or tentatively perennial than the PNW SDAM (42% vs. 17% of sites), contributing to this method’s greater overall error rate (Table 4). Overall, the two SDAMs agreed at 58% of sites.

Table 3. Summary of agreements between streamflow determinations. n: Number of sites. For these analyses, tentative determinations from the NM SDAM were combined with non-tentative determinations. n: Number of sites.

Sites	SDAM	n sampled	n agree	% agreement
All sites	PNW	36	29	81
	NM	36	24	67
Sites with hydrologic data	PNW	19	17	89
	NM	19	13	68

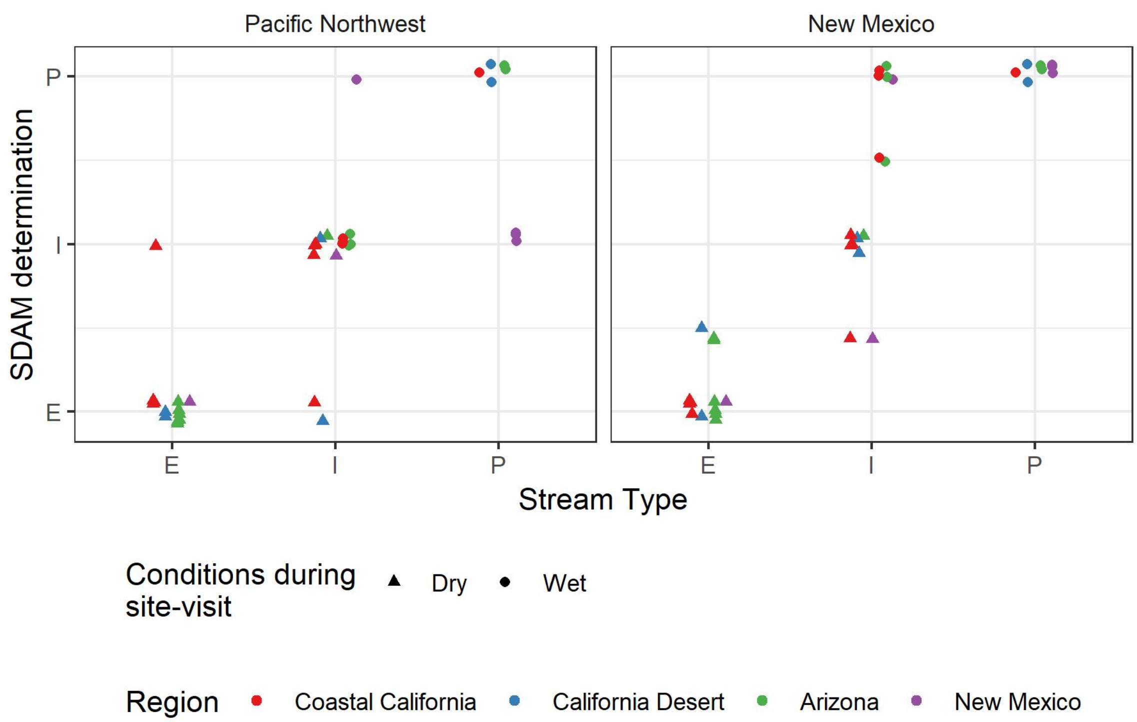

Figure 3. Comparison of determinations by SDAMs with true streamflow duration status. For the NM SDAM, tentative determinations are plotted at the half-way points along the y-axis.

Table 4. Percent correct discrimination of the SDAMs for distinguishing different stream types. Numbers in parentheses indicate numbers of sites.

		Perennial vs.		Ephemeral vs.	
SDAM	Perennial (8) vs. Intermittent (15) vs. Ephemeral (13)	Non-perennial (28)	Wet intermittent (7)	Non-ephemeral (23)	Dry intermittent (8)
PNW	81	89	73	92	86
NM	67	81	53	92	86

Accuracy of the two SDAMs varied by regions and stream types. For example, the PNW SDAM was most accurate in Arizona and the two California regions, whereas the NM SDAM was most accurate in New Mexico and the California Desert (Table 5, Figure 4). Both methods could distinguish ephemeral streams from non-ephemeral streams 92% of the time, and both could distinguish ephemeral streams from dry intermittent streams 86% of the time (Table 4). However, the PNW SDAM could more accurately distinguish perennial from non-perennial streams (89% vs. 81%), as well as perennial from flowing intermittent streams (73% vs. 53%). Notably, the NM SDAM assigned perennial (or tentatively perennial) status to all intermittent sites that were visited during wet conditions, whereas dry intermittent sites were all correctly designated (Figure 3). Errors for the PNW SDAM were more balanced, (14% overestimates vs. 6% underestimates) than the NM SDAM (28% overestimates vs. no underestimates).

Table 5. Accuracy of SDAMs by region and stream type.

		Percent correct	
	n	Pacific Northwest	New Mexico
Region			
Coastal California	12	83	75
California Desert	6	83	83
Arizona	12	100	58
New Mexico	6	33	83
Stream type			
Ephemeral	13	92	77
Intermittent	15	80	53
- Wet	7	86	0
- Dry	8	75	100
Perennial	8	62	100

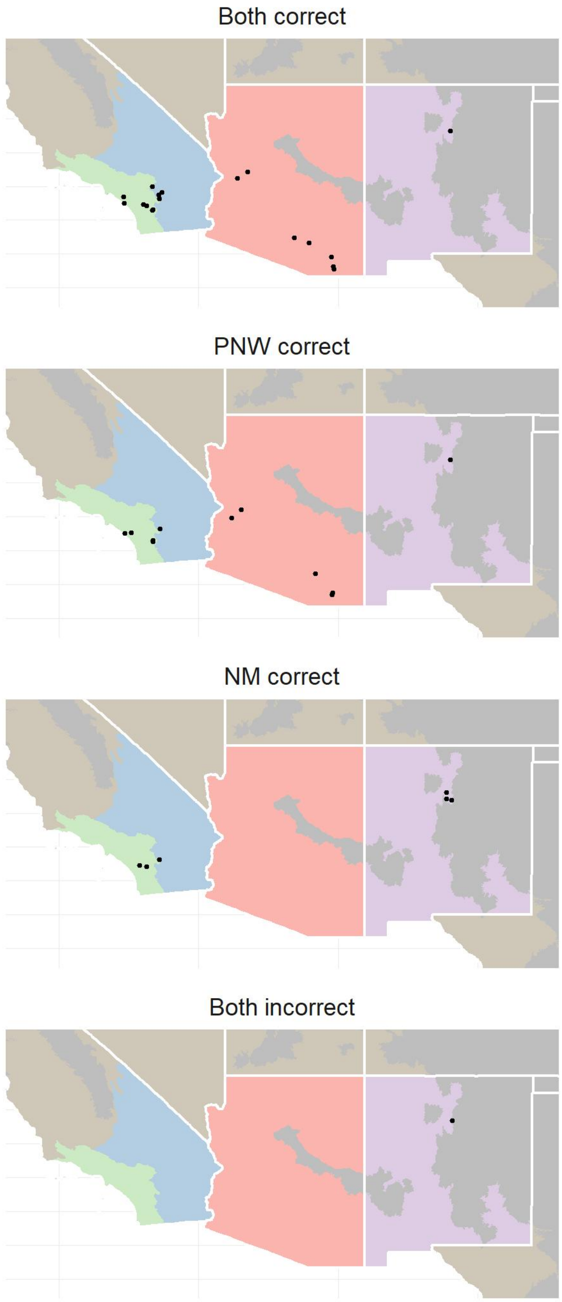

Figure 4. Distribution of correct and incorrect determinations by each SDAM.

Evaluation of individual indicators

Many indicators had significant relationships with the flow duration classes, and were able to discriminate among the three classes, as well as between perennial vs. non-perennial or ephemeral vs. non-ephemeral streams. However, few indicators could discriminate between ephemeral and dry intermittent sites, and even fewer could discriminate between perennial and wet intermittent sites when considered in isolation (Table 6, Figure 5).

Table 6. Agreement between SDAM determinations and true determinations. E: Ephemeral. I: Intermittent. P: Perennial. Smaller text in parentheses indicates the number of tentative determinations from the NM SDAM.

		Pacific Northwest			New Mexico				
Sites		E	I	P	E	I		P	
All sites (determinations from local expertise and hydrologic data)	E	12	1	0	10	3	(3)	0	
	I	2	12	1	0	8	(2)	7	(2)
	P	0	3	5	0	0		8	
Sites with hydrologic data	E	3	1	0	4	0		0	
	I	0	9	0	0	4	(1)	5	(1)
	P	0	1	5	0	0		6	

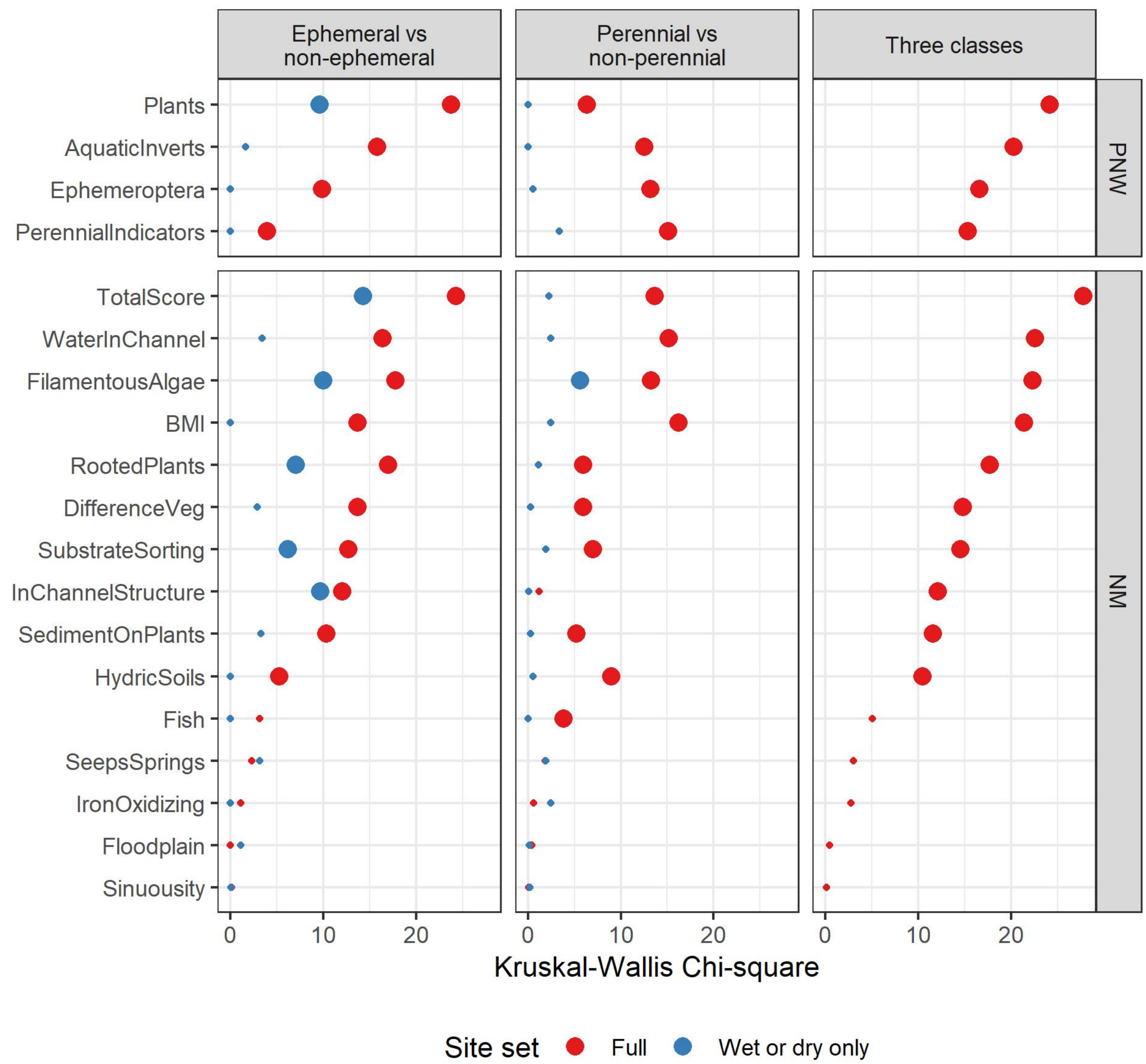

Figure 5. Association between indicators and streamflow classes. Small dots indicate non-significant Chi-squares (p > 0.05). Red dots indicate if the full data set was used, whereas blue dots indicate if just wet sites (for perennial vs. non-perennial) or dry sites (for ephemeral vs. non-ephemeral) were used.

PNW indicators

Most of the indicators associated with the PNW SDAM showed a strong relationship with streamflow duration class (Table 7, Figure 6). In general, the presence of hydrophytic plants and aquatic invertebrates were more effective at discriminating between ephemeral and non-ephemeral streams, whereas the abundance of mayflies and presence of perennial indicator taxa were better at discriminating between perennial and non-perennial streams. However, none were effective in discriminating between perennial and wet intermittent streams, and only one (i.e., hydrophytic plants) could discriminate between ephemeral and dry intermittent streams when considered in isolation (Figure 5).

Table 7. Summary of indicators for the PNW SDAM.

		Number of sites	
Indicator	Stream type	Present	Absent
Aquatic invertebrates	Ephemeral	0	13
	Intermittent	8	7
	Perennial	8	0
6+ mayflies	Ephemeral	0	13
	Intermittent	5	10
	Perennial	7	1
Perennial indicator taxa	Ephemeral	0	13
	Intermittent	1	14
	Perennial	5	3
Hydrophytic plants	Ephemeral	1	12
	Intermittent	13	2
	Perennial	8	0

		Mean	SD
Percent slope	Ephemeral	3.2	2.7
	Intermittent	4.4	4.4
	Perennial	2.6	1.3

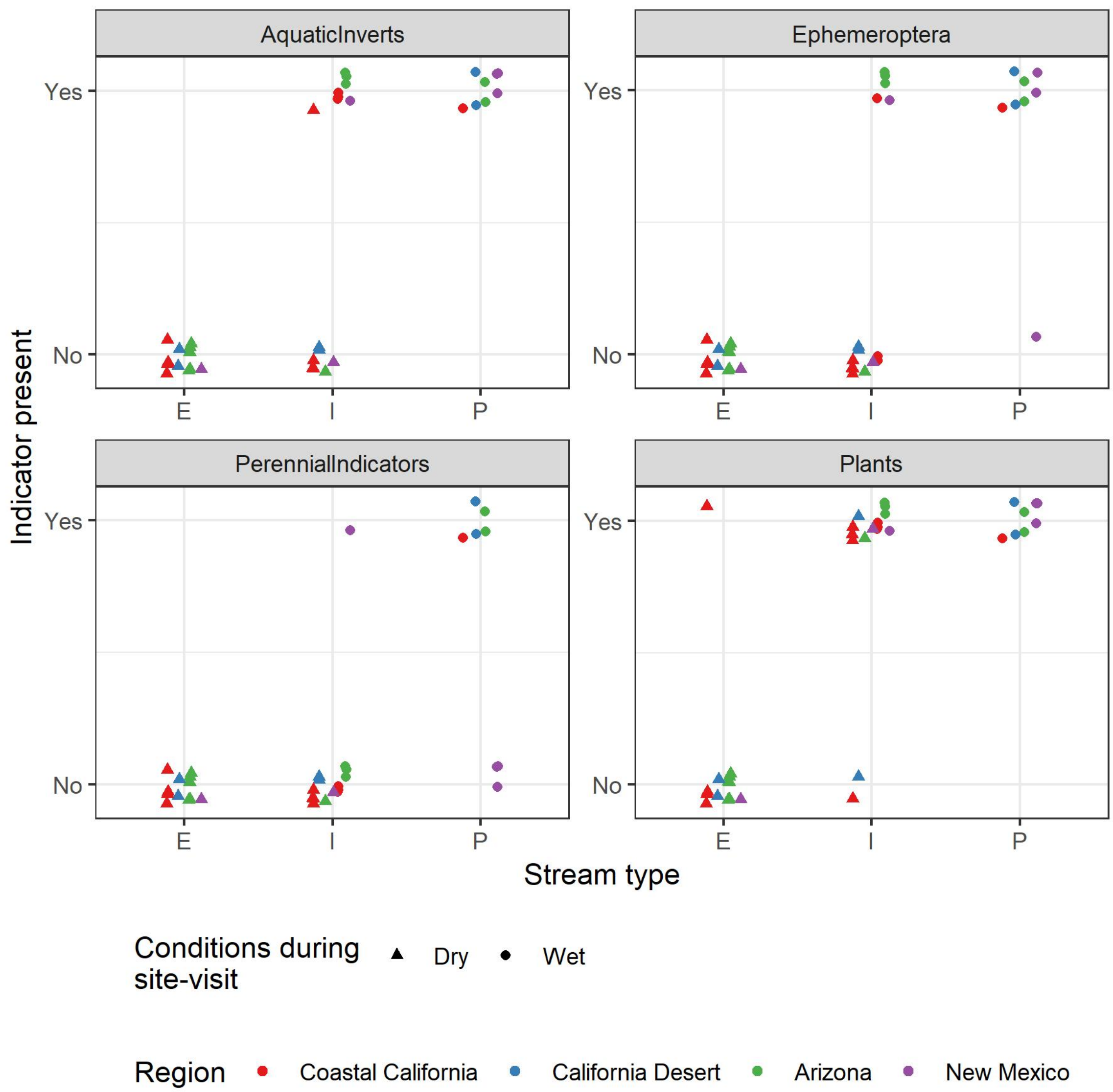

Figure 6. Presence of indicators for the PNW SDAM.

Aquatic invertebrates

Aquatic invertebrates were observed at all perennial streams, as well as all intermittent streams that had surface flow. Signs of aquatic invertebrates (specifically, the pupal case of a caddisfly) were observed at a single dry intermittent site (Upper Agua Caliente Creek in San Diego, CA; Figure 7); it was not possible to determine if this case was from the family Hydropsychidae, which would be considered an indicator of perennial flow (Blackburn and Mazzacano 2012). Aquatic invertebrates were not observed in three sites where a small standing pool (comprising < 1% of the total reach). It was therefore highly effective in discriminating between ephemeral and non-ephemeral sites.

Figure 7. A case of an emerged caddisfly, found in a dry reach (Upper Agua Caliente Creek, San Diego, CA).

Six or more mayflies

This indicator was highly effective in discriminating between ephemeral and non-ephemeral sites, but the absence of mayflies may not reliably discriminate between perennial and intermittent sites. Mayflies were abundant at nearly every site where aquatic insects were observed, with four exceptions that may be due to poor water quality, natural phenology, or inadequate sampling effort to detect them:

> The Lower Santa Fe river (a perennial stream in New Mexico) is dominated by wastewater effluent. Mayflies, caddisflies, and other sensitive taxa are known to be rare or excluded from effluent-dominated rivers in the Arid Southwest. For example, bioassessment samples from the Santa Cruz River at Cortaro Road were devoid of mayflies until 2014, following an upgrade to the wastewater treatment plant (P. Spindler, personal communication). Sampling efforts by the New Mexico Environment department similarly failed to detect mayflies near this location (K. Barrios, personal communication).
>
> San Juan Creek is an intermittent stream in coastal California that is dominated by urban runoff. Excessive algae growth indicative of eutrophication was evident during the site visit. However, nearby Trabuco Creek, a perennial stream within a few kilometers of San Juan Creek, is also dominated by urban runoff, yet it supported abundant mayflies. Trabuco Creek had much higher flows, and presumably better oxygenation, than San

Juan Creek (where only 70% of the reach had observed surface flow); therefore, water quality impacts on this indicator may be moderated by flows. However, bioassessment samples collected in this area contain mayflies (i.e., *Baetis adonis*), suggesting that inadequate sampling may have failed to detect them (4/29/14; data accessed from the California Surface Water Ambient Monitoring Program 6/4/2019).

Mayflies were abundant at the Whitewater River site (a perennial stream in the California Desert) in April, but were very rare during a revisit in August. The lack of development in the watershed (the site meets California's criteria for reference sites; Ode et al. 2016), combined with the presence of other sensitive taxa (e.g., the perennial indicator caddisfly, *Hydropsyche occidentalis*) suggests that the scarcity of mayflies is due to natural phenology rather than pollution or to inadequacies in sampling effort.

Tenaja Creek, an intermittent stream in coastal California, also lacked mayflies. In fact, this site had few aquatic insects at all — only two adult beetles (Dytiscidae: *Liodessus obscurellus* and Hydraenidae: *Hydraena*). Submerged, live and dead algal mats were observed (as well as submerged seedlings of upland plants), suggesting that this site had experienced a period of flow earlier in the winter, followed by a dry spell, yet recently rewet prior to the site visit in April. It is possible that mayflies did not yet have time to recolonize the stream.

Although this indicator likely has utility in discriminating streams with different flow regimes, its sensitivity to pollution may reduce its value in some settings. Additionally, its incorporation of a measure of abundance makes it susceptible to variability in sampling effort, which is not well standardized in the PNW SDAM.

Perennial indicator taxa

This indicator was moderately effective at discriminating between flowing intermittent and perennial sites. However, perennial indicator taxa were not detected at every perennial site, and at the same time were detected at one intermittent site (i.e., the caddisfly Hydropsychidae at Cerro Gordo in New Mexico).

This indicator has the potential to introduce error into the PNW SDAM because 1) the level of sampling effort may be inadequate to document absence of a taxon 2) family-level field identifications require a higher level of training than other indicators, and 3) the decision framework of the PNW SDAM is sensitive to the presence of a single individual. Errors (both false negatives and false positives) are more likely with this indicator than others, and these errors are likely to be consequential for the determination.

Eighteen families of aquatic invertebrates are identified as indicators of perennial flow (Blackburn and Mazzacano 2012), but only six families were encountered in the study (Hydrobiidae, Gomphidae, Corydalidae, Hydropsychidae, and Rhyacophilidae). These taxa were observed at five of eight perennial sites. No perennial indicator taxa were found at the two sites on the Galisteo River, nor the effluent-dominated Santa Fe River, resulting in a determination of "intermittent" at these three sites. It is unclear if more rigorous or more standardized sampling would have detected perennial indicator taxa at these sites.

Although the status of Corydalidae as a perennial indicator taxon in the Arid Southwest has been called into question (Cover et al. 2015, McCune and Mazor 2019), this taxon was only observed at two perennial streams in Arizona, and not at any intermittent streams.

Hydrophytic plants

This indicator was highly effective at discriminating ephemeral from non-ephemeral streams. Hydrophytes were evident at every perennial site and nearly every intermittent site, and were absent from nearly every ephemeral site. The exceptions were all located at sites that represent transitional or intermediate conditions between intermittent and ephemeral flow, underscoring the inherent challenges in classifying streams based on both local expertise and hydrologic data. A few of these sites are highlighted below.

> Pechanga Creek in Coastal California is an ephemeral site, which hardly ever exhibits surface flow, yet the site is dominated by sandbar and red willow (*Salix exigua* and *S. laevigata*, respectively). The streambed is dominated by coarse sand, but the reach is known to overlay a groundwater table that is typically within 10 m of the streambed surface and sometimes as few as 3 m (USGS groundwater Well 332819117070606, downloaded from http://waterdata.usgs.gov/nwis/inventory on 4/30/2019; Figure 8). This high groundwater may be sufficient to support hydrophytes and other ecological characteristics of intermittent streams, despite the lack of surface water.

> Cottonwood Creek in coastal California was designated an intermittent creek based on local expertise (C. Loflen) and data from deployed water level loggers. The site exhibited ephemeral behavior from 2014 through 2016, but flowed for ~2 months in 2017 (year with twice the typical rainfall). During this wetter period, benthic macroinvertebrates were collected, including numerous mayflies, and the perennial indicator caddisfly, *Rhyacophila.* The site was devoid of hydrophytic plants, dominated instead by FAC plants like mulefat (*Baccharis salicifolia*). A single specimen in the genus *Rumex* was discovered. This diverse genus includes plants with a range of wetland indicator status, from UPL to OBL. A species-level identification based on a photograph suggests that this species may have been *R. salicifolius* or *R. triangulivalvis* (status for both: FACW), but this identification was not confident. When the site was evaluated in 2018, dried algal mats were evident, providing an enduring indication of long-lasting flows from the previous year.

> A series of sites on Deep Creek in the California desert were evaluated, representing a gradient from a perennial oasis to a highly ephemeral portion on an alluvial fan. One portion (site code CD_DEEP.I2), classified as intermittent by local expertise (C. Solek) was dominated by upland plants, such as catclaw acacia (*Senegalia greggi*) and desert broom (*Baccharis sarothroids*). The most wetland-adapted plant were California fanpalms (*Washingtonia filifera*, FAC), meaning that no true hydrophytes were evident. As with Cottonwood Creek, dried algal mats were abundant (Figure 9).

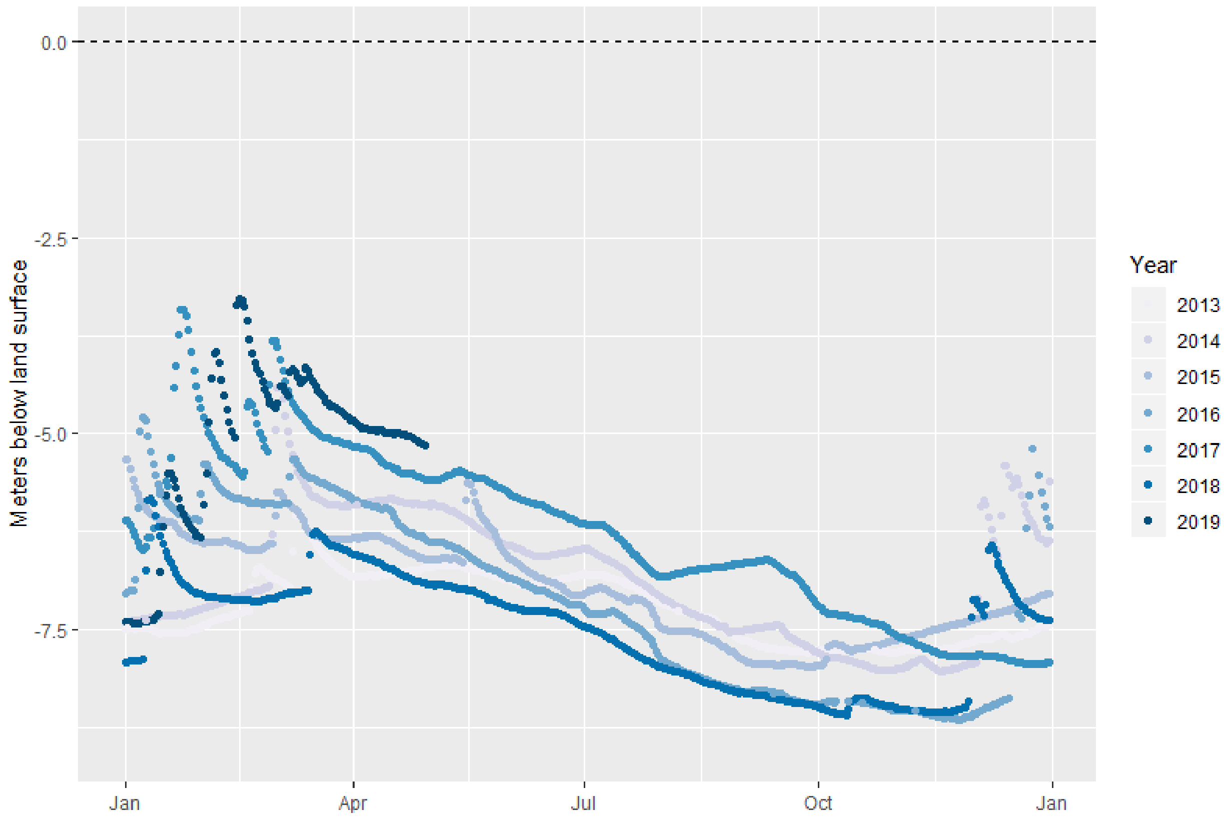

Figure 8. Groundwater level at USGS gauge 332819117070606 near Pechanga Creek. The dashed line represents the level of the land at the well. Data downloaded from http://waterdata.usgs.gov/nwis/inventory?search_site_no=332819117070606.

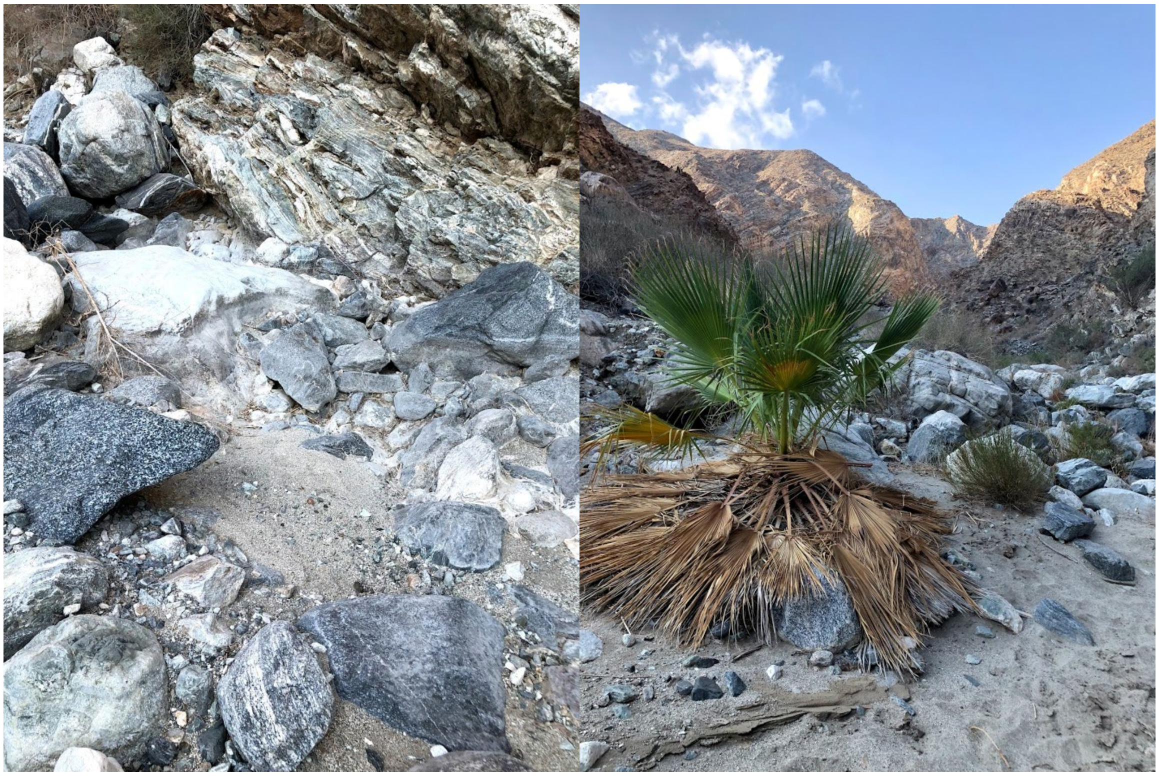

Figure 9. Dried algal mats (left) and non-hydrophytic vegetation (right) in an intermittent portion of a desert stream in California.

Willows were the most common taxon, occurring at 21 of the 22 sites where hydrophytes were encountered (they were not recorded at Agua Caliente Creek, a deeply shaded intermittent site coastal California dominated by other indicators, such as ash and false indigo). Other commonly observed hydrophytes include cattails (8 sites) and white alder (5 sites).

Assessing the presence of hydrophytic plants presents fewer challenges than assessing the presence of perennial indicator taxa. First, although hundreds of plant species are potential wetland indicators in the Arid Southwest, a handful were found at nearly every site, meaning that practitioners may be able to focus on a short list of species they need to recognize. Some genera, such as willows and cattails, have consistent status across species, meaning that species-level identifications are unnecessary. Additionally, voucher specimens and photo records may be more useful for confirming uncertain identifications. Second, hydrophytes are generally conspicuous and widespread, meaning that they are likely to be detected with minimal effort. Although the PNW SDAM is no more robust to errors with this indicator than it is to errors with perennial indicator taxa, the likelihood of errors is substantially lower.

Slope

Slope had no relationship with flow duration. The PNW SDAM uses slope to classify sites as intermittent where hydrophytes are absent, or perennial where perennial indicator taxa are absent (Figure 2). The cutoffs for these classifications (10.5% and 16%, respectively) are higher than observed at most sites. Cottonwood creek, mentioned above, had a slope of 17%; however, this resulted in the PNW SDAM concluding that the site was ephemeral, rather than the correct determination of intermittent. It is possible that the interacting effects of slope and flow duration on field-measured indicators are more prevalent in the Pacific Northwest than in the Arid Southwest.

Other indicators

Fish were observed at 6 sites, including two intermittent sites. Mosquito fish (Gambusia) were observed at most sites, although other species were also observed: an unidentified species at Sabino Canyon (an intermittent site in Arizona) and desert pupfish (*Cyprinodon macularis*) at Thousand Palms (a perennial creek in the California desert). No reptiles or amphibians were observed at any site.

NM SDAM indicators

Some indicators for the NM SDAM had a strong relationship with flow duration, with great fidelity to certain flow duration classes (Table 8, Figure 10). Others either had poor relationships, or were too rarely observed. Although the single highest score for an individual site was an intermittent stream, perennial streams typically scored slightly higher than flowing intermittent sites, and dry intermittent sites typically scored higher than ephemeral sites. In total four indicators could discriminate between ephemeral and dry intermittent sites (i.e., filamentous algae, rooted plants, substrate sorting, and in-channel structure), but only one (i.e., filamentous algae) could discriminate between perennial and wet intermittent sites when considered in isolation (Figure 5). Although the total score was better than any single indicator at discriminating among the three flow classes and could discriminate between ephemeral and dry intermittent sites, it could not discriminate between perennial and wet intermittent sites.

Table 8. Median, minimum, and maximum scores for NM SDAM indicators. Small text indicates minimum and maximum values.

Indicator	Ephemeral			Intermittent: All			Intermittent: Dry			Intermittent: Wet			Perennial		
TotalScore	6.5	1	10	17	10.25	38	14.75	10.25	17	26	19.5	38	29.25	25.5	32.5
Hydrologic indicators															
WaterInChannel	0	0	0	2	0	6	0	0	2	6	3	6	6	6	6
HydricSoils	0	0	0	0	0	3	0	0	0	0	0	3	3	0	3
SedimentOnPlants	0	0	1.5	1	0	1.5	0.875	0	1.5	1.5	1	1.5	1.5	0.5	1.5
SeepsSprings	0	0	0	0	0	1.5	0	0	1.5	0	0	0	0	0	1.5
Biological indicators															
Fish	0	0	0	0	0	3	0	0	0	0	0	3	0	0	2
BMI	0	0	0	0	0	3	0	0	0	3	1	3	3	3	3
FilamentousAlgae	0	0	0	2	0	3	2	0	3	2	0	3	3	2	3
DifferenceVeg	0	0	2	2	0	3	2	0	3	3	2	3	3	0	3
RootedPlants	1	0	3	3	1	3	3	1	3	2.5	2	3	3	2	3
IronOxidizing	0	0	0	0	0	1.5	0	0	0	0	0	1.5	0	0	0
Geomorphological indicators															
Sinuousity	1	0	2	1	0	2	1	0	2	1	1	2	1	0	2
Floodplain	3	0	3	2.25	0	3	1.5	0	3	3	1.5	3	3	0	3
InChannelStructure	0.5	0	2	2	0.5	3	2.5	1	3	1	0.5	3	1.75	1	3
SubstrateSorting	0.5	0	3	2	0.5	3	1.75	1	3	2	0.5	3	3	1.5	3

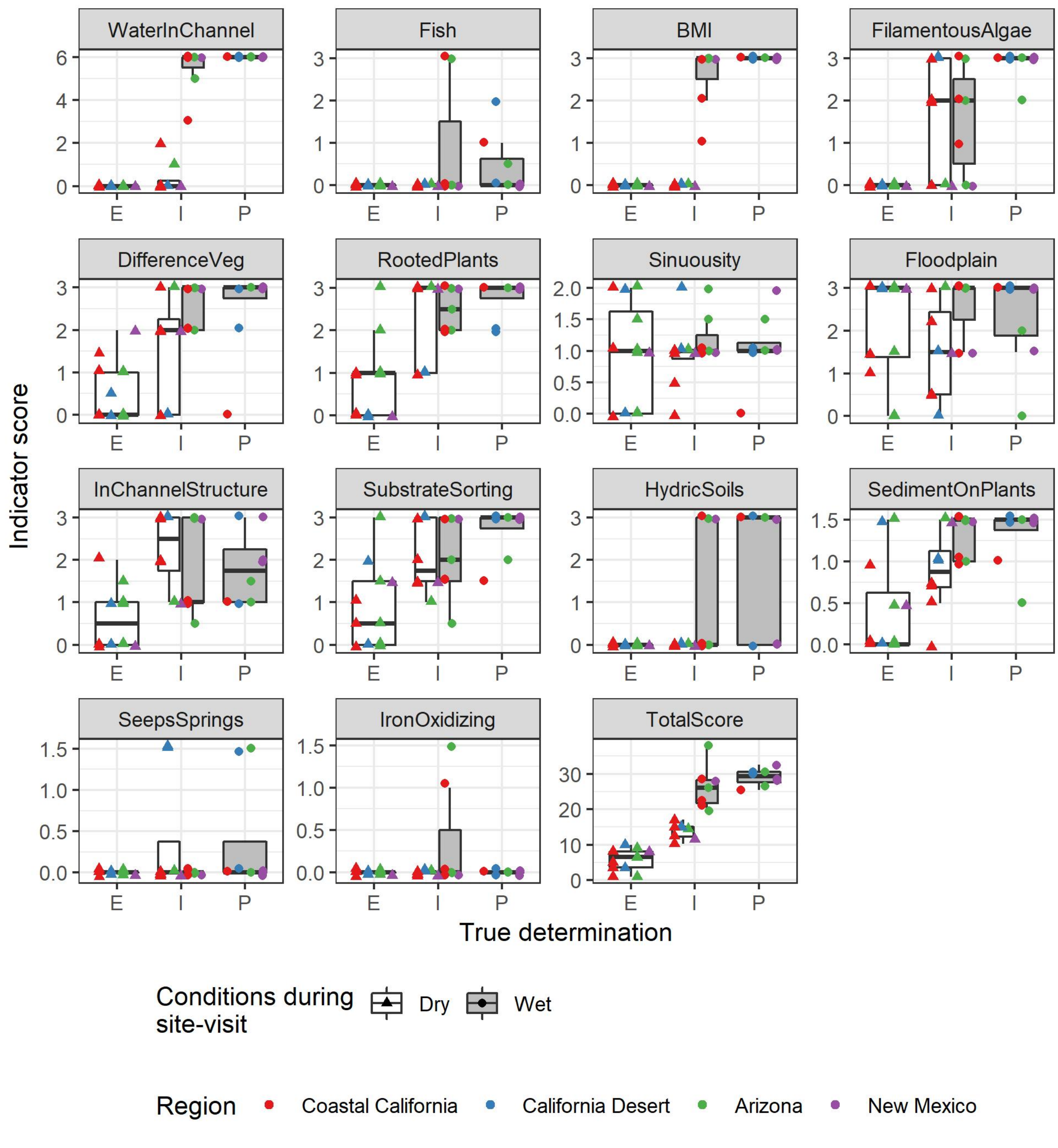

Figure 10. Indicator and index scores for the NM SDAM.

Biological indicators

Biological indicators generally had strong relationships with streamflow duration status. For example, the benthic macroinvertebrate indicator scored zero for every ephemeral and dry intermittent stream, while it scored higher (frequently the maximum) for all other sites. Filamentous algae, differences in riparian vegetation, and rooted plants were also strongly related to flow duration. Notably, algae was the sole indicator that could discriminate between perennial and wet intermittent sites; the lower values recorded at wet intermittent sites may indicate that sample visits may have occurred shortly after the onset of flow at some sites, before algae had the chance to accumulate. In contrast, fish and iron-oxidizing bacteria were too rarely observed to show a relationship with flow duration classes.

Hydrologic indicators

A few hydrologic indicators, showed a good relationship with flow duration class. Specifically, water in channel, and to a lesser extent hydric soils and sediment on plants. However, none of these indicators could discriminate between ephemeral and dry intermittent sites or perennial and wet intermittent sites.

Geomorphic indicators

Substrate sorting and in-channel sequences could discriminate among all three classes of streams, and could also discriminate between ephemeral and dry intermittent sites. In contrast, sinuosity and floodplain and channel dimensions had no evident relationship with flow duration, displaying similar ranges of values at all three types of streams.

Evaluation of SDAM variability

Seasonal variability at the Whitewater River

As noted above, the PNW SDAM identified this perennial site as perennial based on data collected in April 2018, but determined it to be intermittent in August due to the scarcity of mayflies (Table 9). Two perennial indicator taxa (i.e., Hydropsychidae and Gomphidae) were observed during both visits, although one was only detected during the April visit (i.e., Rhyacophilidae). Many of the same hydrophytes were noted on both occasions (e.g., *Alnus oblongifolia*, *Salix exigua*).

Table 9. Indicator measurements at the Whitewater River on two site-visits.

		4/6/2018		8/16/2018
PNW SDAM	Perennial		Intermittent	
Aquatic invertebrates	Yes		Yes	
6+ mayflies	Yes		No	
Perennial indicator taxa	Yes		Yes	
Hydrophytic plants	Yes		Yes	
Slope		5		4
NM SDAM	Perennial		Perennial	
TotalScore		30.5		32.5
Hydrologic indicators				
WaterInChannel		6		6
HydricSoils		3		3
SedimentOnPlants		1.5		1.5
SeepsSprings		0		0
Biological indicators				
Fish		0		0
BMI		3		3
FilamentousAlgae		3		3
DifferenceVeg		2		3
RootedPlants		2		3
IronOxidizing		0		0
Geomorphological indicators				
Sinuousity		1		1
Floodplain		3		3
InChannelStructure		3		3
SubstrateSorting		3		3

By contrast, the NM SDAM correctly identified this site as perennial on both site visits. The total score increased from 30.5 to 32.5. Many indicators had the exact same values. As exceptions, differences in vegetation and absence of rooted plants in the streambed both scored higher in August than in April, perhaps reflecting seasonal changes in these indicators (Table 9).

Comparison with data collected by the New Mexico Environment Department

Of the 6 sites assessed in New Mexico, five received the same determination derived from NMED's data (Table 10). An intermittent site, Frenchie Creek, was incorrectly determined to be ephemeral by NMED's data (total score: 7.5), but tentatively intermittent with data collected for this project (11.5). Despite this consistency in final determinations, there was a clear tendency in this pilot study to score indicators higher than NMED (Table 11). This bias was particularly evident for sediment on plants, benthic macroinvertebrates, differences in vegetation, and in-channel structure. Only one indicator (i.e., sinuosity) was more likely to be underestimated than overestimated. Such differences may reflect practitioner bias, which may greatly influence the highly subjective measurement of indicators for the NM SDAM. However, in some cases it may reflect long-term changes in site conditions. For example, Galisteo Creek at Galisteo was given a score of 3 for filamentous algae based on the abundance of growth observed at the site on 6/11/2018 (Figure 11), yet this site scored 0 by NMED on 9/9/2008. It is unlikely that observer bias alone accounts for such a difference. Possibly, NMED visited the site following storm events that flushed filamentous algae from the reach.

Table 10. Data collected by the New Mexico Environment Department (NM) or by Raphael Mazor (RM).

Site	Cerro Gordo			Chamiso		Frenchie		Galisteo at Galisteo		Galisteo at Cerrillos				Santa Fe River	
Stream type	Intermittent			Ephemeral		Intermittent		Perennial		Perennial				Perennial	
Evaluator	NM	NM	RM	NM	RM	NM	RM	NM	RM	NM	NM	NM	RM	NM	RM
Date	5/13/2009	5/22/2012	6/11/2018	6/25/2008	6/11/2018	6/26/2008	6/11/2018	9/9/2008	6/11/2018	9/9/2008	10/1/2010	12/2/2010	6/11/2018	6/25/2008	6/11/2018
Final det.	PT	PT	P	E	E	E	IT	P	P	PT	PT	P	P	P	P
TotalScore	21	21.5	28	2	8	7.5	11.5	22.8	28.5	20.5	21	18	32.5	28.5	28
Hydrologic indicators															
Water In Channel	6	6	6	0	0	0	0	6	6	6	4	6	6	6	6
HydricSoils	0	0	3	0	0	0	0	3	0	0			3	3	0
Sediment On Plants	0.75	1	1.5	0	0.5	0.5	1.5	0.75	1.5	0.75			1.5	0.5	1.5
Seeps/ Springs	0		0	0	0	0	0	0	0	0			0	2	0
Biological indicators															
Fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BMI	1	2	3	0	0	0	0	2	3	1	3	3	3	3	3
Algae	1	0	0	0	0	0	0	0	3	2	3	3	3	3	3
Difference in Veg	2.5	3	3	0	2	1.5	2	0	3	3	3	3	3	3	3
Rooted Plants	2.5	3	3	1	0	3	3	3	3	2	3	3	3	3	3
Iron-Oxidizing	0		0	0	0	0	0	0	0	0			0	0	0
Geomorphological indicators															
Sinuosity	1.75	1	1	1	1	1	1	1	1	1	2		2	2	1
Floodplain	3	0	1.5		3		1.5	3	3	1.5	3		3		1.5
In-Channel Structure	1	2.5	3	0	0	0	1	1	2	1	0		2	1.5	3

Substrate Sorting	1.5	3	3	0	1.5	1.5	1.5	3	3	2.2			3	1.5	3

Table 11. Comparison of indicator scores between the New Mexico Environment Department (NMED) and Raphael Mazor (RM).

	Comparison of RM vs. NMED		
Indicator	Lower	Equal	Higher
TotalScore	1	0	5
Hydrologic indicators			
WaterInChannel	0	6	0
HydricSoils	2	2	2
SedimentOnPlants	0	0	6
SeepsSprings	1	5	0
Biological indicators			
Fish	0	6	0
BMI	0	3	3
FilamentousAlgae	1	3	2
DifferenceVeg	0	2	4
RootedPlants	1	3	2
IronOxidizing	0	6	0
Geomorphological indicators			
Sinuousity	2	3	1
Floodplain	1	1	1
InChannelStructure	0	1	5
SubstrateSorting	0	2	4

Figure 11. Abundant filamentous algae at Galisteo Creek in Galisteo, NM.

DISCUSSION

Although the dynamism of stream ecosystems in the ASW make the prospect of rapid streamflow duration assessment a daunting task, this pilot study demonstrates that accurate assessments are possible. Both the NM and PNW methods show promise and offer a starting point for creating a method that may be used across the entire region. The accuracy of the PNW method was similar in this study (81%) to the accuracy reported in its development (84%, from Table 5 Nadeau et al. 2015), whereas the observed accuracy for the NM method (67%) was lower than reported in its development (85%). The two methods take different approaches towards assessment that have different benefits and disadvantages that should be considered before developing a tool for the entire ASW.

The PNW has many advantages favoring its use as a streamflow duration method. This method is based on a decision tree and relies on just a few, easily measured indicators. The measurement of these indicators is entirely objective; although training is required for their measurement (e.g., training to make correct taxonomic identifications), these measurements are highly repeatable by different practitioners. Application of the data to the decision tree (Figure 2) is simple, and it can be easily executed in the field with little opportunity for error. The indicators used in this method are primarily biological and have a direct and defensible relationship with flow duration (the one exception, slope, is used to modify interpretation of these biological indicators; McCune and Mazor 2019). The primary disadvantage of the PNW method is that the decision tree is not robust to variability or to practitioner error. The presence of a single indicator can entirely change the outcome of an assessment, as we observed with the two visits to the Whitewater

River where the absence of perennial indicator taxa led to the wrong conclusion that the site was intermittent.

In contrast, the NM method represents a different set of advantages and disadvantages that set it apart from the PNW method. The NM method evaluates a much wider range of indicators than the PNW method, including several geomorphological and hydrologic indicators. We demonstrate the utility of some of these indicators in discriminating ephemeral from non-ephemeral streams (Figure 5). However, few have a defensible relationship with streamflow duration (particularly the geomorphological or hydrologic indicators), more appropriately reflecting stream power (McCune and Mazor 2019). Whereas the PNW method uses a simple decision tree, the NM method requires calculation of an index, where scores are compared to threshold values for each flow duration class (Table 2). The advantage of an index over a decision tree is that it can better account for variability and is more robust to practitioner error. Thus, whereas the PNW drew the wrong conclusion about the Whitewater River, scores for the NM index were similar in the two site-visits. A minor disadvantage of the index approach is that it requires calculation, opening the door to errors (particularly when calculated in the field). A more concerning disadvantage is that many of the NM method indicators are subjectively scored and may be greatly influenced by practitioner experience. Revised guidance, training, and intercalibrations may improve repeatability of these indicators if they are used in an ASW method.

Streamflow duration represents a complex, multidimensional gradient, which creates a challenge for any effort to classify streams according to a few simple classes. Environmental management that doesn't adequately account for the complex and variable nature of streamflow in arid regions is likely to lead to contentious or undesirable outcomes. Streams, particularly in arid climates, are dynamic systems exhibit different patterns in different years (Gasith and Resh 1999). Even within this limited pilot studies, many sites were transitional, exhibiting characteristics that make it difficult to assign them to one class. Streams like Cottonwood Creek and Deep Creek may appear to be ephemeral in most years, yet in wet years sustain flows for weeks or months. Another site, Pechanga Creek, rarely showed evidence of surface flows, yet local groundwater conditions were sufficient to sustain hydrophytes and other indicators of long-duration flow. This dynamism should favor the use of biological indicators, which have the ability to integrate and reflect long-term and variable flow conditions over indicators that are highly influenced by the most recent flood event (e.g., sediment deposition on plants). Long-lived indicators, such as many hydrophyte species, may be particularly useful for integrating long-term conditions at a site and can provide context for interpreting shorter-lived indicators, like several benthic macroinvertebrates. A rapid streamflow duration assessment method for the ASW can provide valuable information, both for policy decisions that require classification in simple categories, as well as for management decisions that require more nuanced consideration of these dynamic ecosystems.

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APPENDICES

Appendix 1. Aquatic invertebrates designated as perennial indicator taxa in the Pacific Northwest

The following taxa are considered to be indicators of perennial flow duration for streams in the Pacific Northwest (Blackburn and Mazzacano 2012).

Group	Family	Life-stage
Mollusks	Pleuceridae	Any
	Ancylidae	Any
	Hydrobiidae	Any
	Margaritiferidae	Any
	Unionidae	Any
Caddisflies	Rhyacophilidae	Larvae and pupae
	Philopotamidae	Larvae and pupae
	Hydropsychidae	Larvae and pupae
	Glossosomatidae	Larvae and pupae
Stoneflies	Pteronarcyidae	Larvae
	Perlidae	Larvae
Beetles	Elmidae	Larvae
	Psephenidae	Larvae
Dobsonflies	Corydalidae	Larvae
Dragonflies and damselflies	Gomphidae	Larvae
	Cordulegastridae	Larvae
	Calopterygidae	Larvae