



# Developing a Monsoon Impact Index

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The purpose of this document is to outline a strategy for developing a scale that quantifies monsoon impact. The document introduces relevant **factors** for doing this, considers several **combinations** of factors, discusses **main factors**, and then **proposes** an initial scale to serve as a starting point for development. The document concludes with personal **considerations**.

## FACTORS

It is believed that there are four primary potential measures of monsoon impact in Arizona:

1. Drought, as characterized by the [Drought Monitor](#)
2. Streamflow
3. Reservoir Volume
4. and Agricultural Productivity: specifics TBD

a fifth factor, Precipitation, while highly characteristic of the monsoon, does not alone characterize a physical impact.

Year	Average AZ Precipitation (in)	AZ Change in Drought Monitor	AZ Average Streamflow (ft <sup>3</sup> /s)	AZ Average Change in Reservoir Volume	AZ Agriculture impacts
2020	1.03*	2.95*	20.32	TBD	TBD
2019	3.02	1.97	37.81		
2018	4.99	-0.52	82.61		
2017	4.78	-0.03	94.01		
2016	5.61	-0.24	66.27		
2015	5.31	-0.39	87.60		
2014	7.05	-0.65	150.98		
2013	6.95	-1.15	250.29		
2012	4.97	-0.58	86.33		
2011	4.76	0.43	66.77		
2010	4.29	0.28	171.53		
2009	2.38	0.77	32.63		
2008	4.49	-0.62	106.39		
2007	4.17	-0.67	173.36		
2006	5.52	-1.41	379.72		
2005	4.03	-0.29	91.60		
2004	3.49	-0.02	80.14		
2003	3.44	-0.43	87.57		
2002	3.95	-0.4	137.23		
2001	3.58	0	67.93		
2000	3.66	-0.03	48.65		

\* as of September 22, 2020

**Table 1:** Primary potential measures of monsoon impact in Arizona

## **COMBINATIONS**

Of the various factors, there are many possible combinations that could be utilized to produce a monsoon impact index. Further research is needed to determine the relative significance of each factor. It was initially proposed in this project that an impact index could incorporate all of the factors; however, it appears that the Drought Monitor already factors in USGS Weekly Streamflow Percentiles and Standardized Precipitation Index. Because of this, it is unclear to what extent directly incorporating streamflow and/or precipitation with data from the Drought Monitor would be redundant. If further investigation indicates redundancy with these three factors, then it is recommended that Change in Drought Monitor, Change in Reservoir Volume, and yet to be determined Agricultural measures be utilized.

## MAIN FACTORS

It is believed that the Drought Monitor and Reservoir Volume will be most useful for developing a Monsoon Impact Index.

### **The Drought Monitor:**

The Drought Monitor, [droughtmonitor.unl.edu](http://droughtmonitor.unl.edu), expresses severity of drought by characterizing regions as None, D0 (Abnormal), D1 (Moderate), D2 (Severe), D3 (Extreme), or D4 (Exceptional). Within each geographic domain, the percentage covered by each category is given. By assigning a number 0 to 5 to each category, i.e. 0 to “None” and 5 to “D4 (exceptional)”, and multiplying the assigned numbers by the percentage of area covered by the corresponding drought category, the resulting numbers can be summed to produce an overall average drought level for the region. The change in average Drought Monitor level, or drought index, over the course of the monsoon season is indicative of the monsoon impact on drought. The values of change will range from 5 (deterioration from no drought to D4 Exceptional drought) to -5 (improvement from D4 Exceptional drought to no drought).

<b>Calculating 2020 Chance in Drought Monitor</b>					
<u>Assigned Number</u>	<u>Drought Index Category</u>	June 2, 2020		September 29, 2020	
		Percent Area Covered	Assigned Number x Percentage	Percent Area Covered	Assigned Number x Percentage
0	None	80.51	0	0	0
1	D0	5.82	0.0582	0	0
2	D1	6.91	0.1382	6.03	0.1206
3	D2	6.76	0.2028	24.02	0.7206
4	D3	0	0	66.58	2.6632
5	D4	0	0	3.37	0.1685
<b>Average Statewide Drought Index:</b>			<b>0.3992</b>	<b>3.6729</b>	
<b>Arizona change in the Drought Monitor during 2020 Monsoon Season:</b>				<b>3.27</b>	

**Figure 1:** Calculating Arizona’s change in drought level throughout the 2020 Monsoon Season. The average statewide drought index increased from 0.39 (None) to 3.67 (D3 Extreme). The total change in the Drought Monitor was 3.27.

### Pros of utilizing the Drought Monitor:

- Multiple variables seem to be incorporated, including: Palmer Drought Severity Index, CPC Soil Moisture, USGS Weekly Streamflow, and Standardized Precipitation Index

- The data updates in regular weekly intervals
- The data is easily accessible
- Data is available at the state (2000-) and CWA (2017-) geographical levels

**Cons** of utilizing the Drought Monitor:

- Its usefulness is limited to years where persistent drought is present
- Years where drought was never present and never developed will be reflected by a value of “0” regardless of the monsoon intensity
- Years where drought resolved before the end of the monsoon season may under-characterize monsoon influence

It is believed that by combining the change in Drought Monitor with change in Reservoir Volume, the cons associated with the Drought Monitor can be overcome.

**Reservoir Volume:**

Similar to the Drought Monitor, the change in volume of reservoirs over the monsoon season can be calculated. This change can be used to quantify the impact that the monsoon has on regional water storage. Due to time spent analyzing streamflow, and an apparent lack of a centralized reservoir database, actual reservoir data was unable to be analyzed during the two-week timeframe of this project. However, the process is expected to be analogous to calculating the change in Drought Monitor.

**Pros** of utilizing Reservoir Volume:

- Represents a significant direct impact of the monsoon
- Unless all reservoirs in the state are either completely dry or completely full, the measure can apply to all years

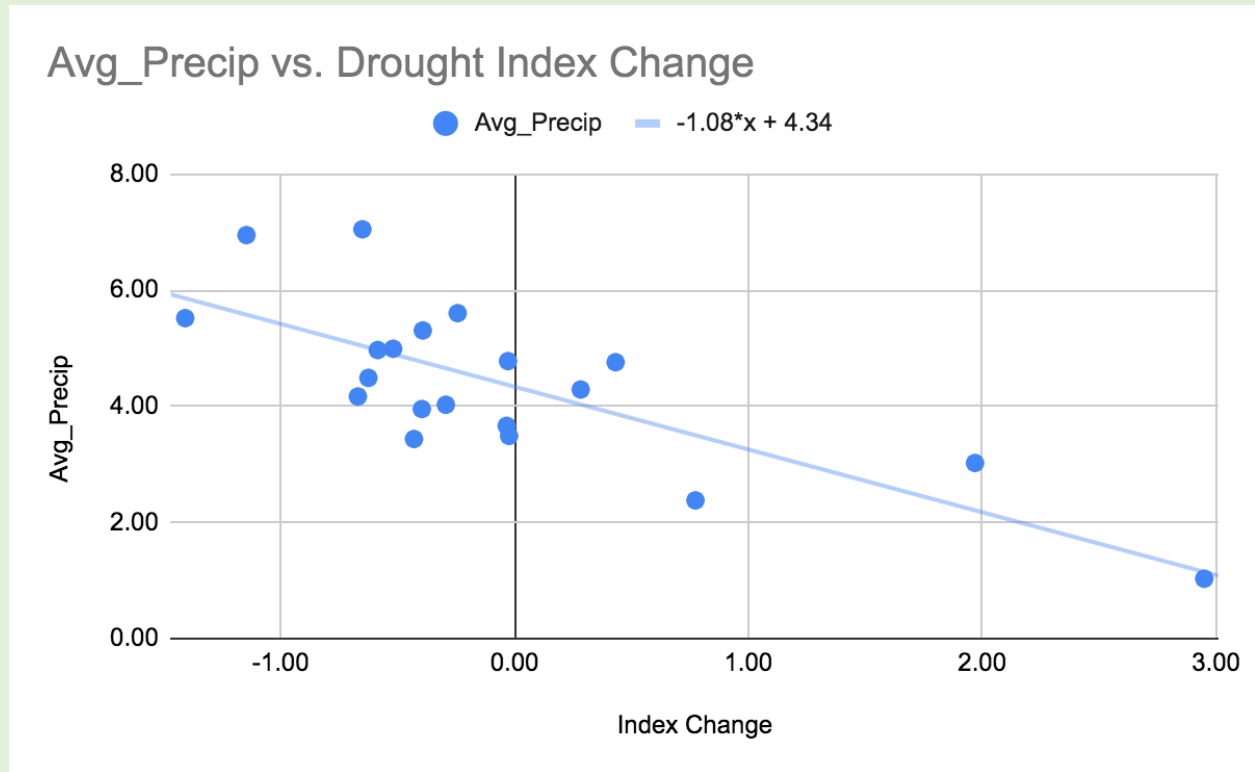
**Cons** of utilizing Reservoir Volume:

- There does not appear to be a centralized location for the data – it must be manually tracked down and compiled
- Unlike the Drought Monitor, the Reservoir Data is not necessarily reflective of the entire geographical area, rather each reservoir at most represents one watershed
- Specific reservoirs must be strategically chosen to be part of the index

Due to the second con of utilizing reservoir volume, it is also suggested that a Monsoon Impact Index consider incorporating measures of agricultural productivity. While it is known that these kinds of measures exist at places such as [quickstats.nass.usda.gov](http://quickstats.nass.usda.gov), deciding which measures are most significance is beyond the scope of this individual’s knowledge. It is also unknown how frequently any relevant data is updated. It is recommended that individuals familiar with the agricultural sector be consulted.

## PROPOSAL

It is proposed that the Drought Monitor be utilized as a baseline impact scale and that the other elements of Reservoir Capacity and Agricultural Productivity be incorporated during future development.



**Figure 2:** The 2000 to 2020 relationship between the Average Precipitation accumulated at Arizona NWS Climate Sites vs the Change in Drought Monitor during the monsoon seasons as of September 22, 2020. The 2020 Monsoon season is the point in the bottom right. Coefficient Correlation:  $R = 0.77$ .

Classification	Change in Drought Monitor	Characterization
M4	1.5 to 5	"Significantly drying conditions"
M3	0.5 to 1.5	"Drying conditions"
M2	-0.5 to 0.5	"Minimally-changing conditions"
M1	-0.5 to -1.5	"Moistening conditions"
M0	-1.5 to -5	"Significantly moistening conditions"

**Figure 3:** Proposed Monsoon Impact Scale categories based solely on the change in Drought Monitor. The classification ranges are based solely on association with the drought levels in the drought monitor, i.e. a change in drought monitor of  $\pm 1.0$  is associated with one full change in drought status – ex: “D2 Severe Drought” to “D3 Extreme Drought” or vice versa.

Year	Classification	Drought Monitor Change	Average Precipitation	Characterization
2020	M4	2.95*	1.03*	"Significantly drying conditions"
2019	M4	1.97	3.02	"Significantly drying conditions"
2018	M1	-0.52	4.99	"Moistening conditions"
2017	M2	-0.03	4.78	"Minimally-changing conditions"
2016	M2	-0.24	5.61	"Minimally-changing conditions"
2015	M2	-0.39	5.31	"Minimally-changing conditions"
2014	M1	-0.65	7.05	"Moistening conditions"
2013	M1	-1.15	6.95	"Moistening conditions"
2012	M1	-0.58	4.97	"Moistening conditions"
2011	M2	0.43	4.76	"Minimally-changing conditions"
2010	M2	0.28	4.29	"Minimally-changing conditions"
2009	M3	0.77	2.38	"Drying conditions"
2008	M1	-0.62	4.49	"Moistening conditions"
2007	M1	-0.67	4.17	"Moistening conditions"
2006	M1	-1.41	5.52	"Moistening conditions"
2005	M2	-0.29	4.03	"Minimally-changing conditions"
2004	M2	-0.02	3.49	"Minimally-changing conditions"
2003	M2	-0.43	3.44	"Minimally-changing conditions"
2002	M2	-0.40	3.95	"Minimally-changing conditions"
2001	M2	0.00	3.58	"Minimally-changing conditions"
2000	M2	-0.03	3.66	"Minimally-changing conditions"
* as of September 22, 2020				

**Figure 4:** Characterization of all monsoon seasons since 2000 based solely on change in drought monitor.

**Limitations:** As noted in the cons of utilizing the drought monitor, excessively moist conditions are not adequately captured by this scale. Years when drought resolved before the end of the monsoon season *may* under-characterize monsoon influence, and years when drought conditions were not present at the season beginning nor end *will* be under-characterized. It is believed that by incorporating the change in Reservoir Volume, the moist end of this spectrum can be better represented through elevated reservoir levels. It is also believed that any measures of agricultural productiveness will be reflective of the entire wet-dry spectrum, i.e. too little rain and too much rain for agricultural productivity.

The following scale utilizes average Arizona streamflow as **a temporary proxy for Reservoir Volume** to illustrate how a combined Drought Monitor / Reservoir Volume scale may look:

Combined Drought Monitor and Streamflow scale					
= (Drought Monitor Change x -1 + 5) x (Average Streamflow / 100)					
Year	Combined Drought Monitor and Streamflow scale	Drought Monitor Change	Average Streamflow	Classification	Characterization
2020	0.4	2.95	20.3	TBD	TBD
2019	1.1	1.97	37.8		
2009	1.4	0.77	32.6		
2000	2.4	-0.03	48.7		
2011	3.1	0.43	66.8		
2001	3.4	0	67.9		
2016	3.5	-0.24	66.3		
2004	4.0	-0.02	80.1		
2018	4.6	-0.52	82.6		
2015	4.7	-0.39	87.6		
2017	4.7	-0.03	94.0		
2003	4.8	-0.43	87.6		
2012	4.8	-0.58	86.3		
2005	4.8	-0.29	91.6		
2008	6.0	-0.62	106.4		
2002	7.4	-0.4	137.2		
2010	8.1	0.28	171.5		
2014	8.5	-0.65	151.0		
2007	9.8	-0.67	173.4		
2013	15.4	-1.15	250.3		
2006	24.3	-1.41	379.7		
Category divisions TBD based on physical impacts associated with scale					

**Figure 5:** This combined scale multiplies the Drought Monitor Change and Average Streamflow. The Drought Monitor Change is adjusted by changing the sign of the value then adding 5, so the driest possible Drought Monitor change is 0 and the wettest possible Drought Monitor change is 10. Combined with streamflow, higher scale values are associated with wetter conditions and lower scale values are associated with drier conditions. More impact-based correlation research is needed to understand the significance of these values in order to establish meaningful category/classification divisions.

## CONSIDERATIONS

### **Impacts:**

This research and proposal has sought to rely solely on physical impacts to quantify monsoon significance. The three main factors considered, Drought Monitor, Reservoir Volume, and Agricultural Productivity all provide useful means of expressing impacts. However, I strongly believe that this is not enough. When completed, the finished Monsoon Impact Scale must be characterized in ways that express potential specific impacts within each category. We must ask, **“what does each category imply about physical impacts to streams, reservoirs, agriculture, and other aspects of society?”** The answers to this question itself may inspire the incorporation of additional metrics into the finalized scale.

### **Characterization:**

Significant consideration needs to be given to the characterization of the final scale categories. It is my belief that part of the reason scales such as the Richter, Saffir-Simpson, and Fujiwara are so widely utilized is because they only consider one element. Because of this they are very easy for the public to interpret. Unless the proposed Monsoon Impact Index utilizes only one variable (Reservoir Volume is recommended if this is considered), it will be relatively complex. The goal should be to develop a product that, while internally complex, has a very simplified public-facing end, such as the Regional Snowfall Impact Scale: [ncdc.noaa.gov/snow-and-ice/rsi/nesis](https://www.ncdc.noaa.gov/snow-and-ice/rsi/nesis). Strengths and weaknesses of the snowfall impact scale and others like it should be explored to improve the viability of any monsoon impact index. Extensively outlining the impacts that correspond to all proposed monsoon impact categories may increase overall understanding and reception of the scale.

### Notes:

- Average precipitation was based on NWS Climate Sites, excluding Mesa which only has a two-year archive.
- Average Streamflow was derived from [Chinle Creek near Mexican Water](#), [Little Colorado River near Cameroon](#), [Little Colorado River at Woodruff](#), [Verde River near Camp Verde](#), [Agua Fria River near Rock Springs](#), [Salt River near Roosevelt](#), [Gila River at Calva](#), [Santa Cruz River at Trico](#), and [Gila River at Dome](#). These locations were considered to best represent streamflow at the state level.