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U.S. Department of Homeland Security

Federal Emergency Management Agency

Methodology for Aquifer Storage and Recovery Benefit Cost Analysis

Prepared for:

U.S. Department of Homeland Security
Federal Emergency Management Agency

By: CDM Federal Programs Corporation

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CDM Smith

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Acronyms

ASR	aquifer storage and recovery
BCA	benefit-cost analysis
BCR	benefit-cost ratio
DLF	drought loss factor
DOI	duration of impact
FEMA	Federal Emergency Management Agency
HMA	Hazard Mitigation Assistance
LWS	loss of water service
mgd	million gallons per day
O&M	operation and maintenance
OGSI	Opportunity, Growth, and Security Initiative
RI	recurrence interval
SSY	system supply yield
US	United States

Section 1

Overview

1.1 Introduction

The President's 2015 Opportunity, Growth, and Security Initiative (OGSI), Executive Order 13653 Preparing the United States for the Impacts of Climate Change, the President's 2013 Climate Action Plan, the Federal Emergency Management Agency's (FEMA's) Climate Change Adaptation Policy, and the 2014-2018 FEMA Strategic Plan, all identify the risks and impacts associated with climate change on community resilience to natural hazards and direct federal agencies to support climate resilient infrastructure.

FEMA is encouraging communities to incorporate methods to mitigate the impacts of climate change into eligible Hazard Mitigation Assistance (HMA) funded risk reduction activities by providing guidance on Climate Resilient Mitigation Activities, including aquifer storage and recovery (ASR). FEMA encourages communities to use this information in developing eligible HMA project applications that leverage risk reduction actions and increase resilience to the impacts of climate change.

Historically, the bulk of mitigation funded through FEMA's HMA programs has been related to flood mitigation. However, with increased frequency and duration of water shortages related to drought and magnified by impending climate change, FEMA is expanding its role into the area of drought mitigation.

The National Weather Service (2012) defines drought, as follows:

> *Drought is a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage causing adverse impacts on vegetation, animals, and/or people. It is a normal, recurrent feature of climate that occurs in virtually all climate zones, from very wet to very dry. Drought is a temporary aberration from normal climatic conditions, thus it can vary significantly from one region to another.*

Just as drought varies by location so does a municipal water utility's risk for water shortage due to drought. Consider two adjacent municipalities, one utility may have a more resilient water supply compared to their neighbor due to a number of factors, including legal, infrastructure, and hydrologic constraints. These unique, "system-specific" constraints must be considered and thus prohibit a pre-calculated approach for performing benefit-cost analysis (BCA) of a drought mitigation project. Instead, a more tailored analysis is required that takes into account not only a region's drought risk but a specific municipality's unique risk for water shortages in the face of drought.

FEMA has identified ASR as a mitigation strategy that is eligible for grant funding under the HMA program. The goal of this report is to describe and discuss a methodology that subapplicants can use to analyze the impact of water shortages due to drought and estimate the benefits of an ASR project for the purpose of applying for HMA funding. **Section 2** provides high-level background information on ASR and drought. **Section 3** details the proposed methodology for performing a BCA for ASR as it relates to drought mitigation. **Section 4** includes step-by-step instructions for using the ASR BCA spreadsheet tool. Lastly, **Section 5**, provides concluding remarks to FEMA regarding the proposed ASR BCA methodology.

Section 2

Background

This section includes background information on use of ASR as a drought mitigation strategy. Additional background information related to ASR, as well as programmatic concerns, can be found in the *Supplement to FEMA Mitigation Support for Planning and Implementation of Climate Resilient Infrastructure* (CDM Smith 2015). This report, the proposed methodology (**Section 3**), and resulting tool (**Section 4**) build upon this previous work.

2.1 Drought Mitigation through ASR

ASR is capturing water when it is abundant, such as during a rainy season or spring snow melts, storing the water in the subsurface in brackish aquifers, and recovering the water when needed. There are two types of aquifers, confined and unconfined. A confined aquifer is one in which an impermeable soil/rock layer exists that prevents water from seeping into the aquifer from the ground surface located directly above. ASR projects in confined aquifers can only be recharged using an injection well. An unconfined aquifer can be recharged either by using an injection well or by allowing surface water to infiltrate and seep into the aquifer. The appropriate method of recharge, and source and treatment of water added to an aquifer, should be based on specific site conditions.

ASR projects provide several advantages as a method to increase water supply for drought mitigation. Since ASR is a subsurface storage technology, it is more resilient and protected than more traditional storage technologies such as reservoirs or surface impoundment. For example, water stored in an ASR system has increased protection from evaporation, surface pollutants, and extreme weather events. Also, unlike reservoirs, there is not potential for levee failure and downstream flooding. ASR can also be used to protect freshwater supplies along coastal areas as a barrier or protection from saltwater intrusion.

ASR does have a unique set of challenges that must be addressed. These challenges include site-specific conditions, source water quantity and quality, and the potential for contamination of the underground water supply (e.g., leaching of arsenic from aquifer formations). Project applicants must address all potential impacts to hydrologic and environmental resources and provide the information necessary for FEMA to ensure compliance with environmental requirements. It is recommended that applicants consult with technical experts in developing an ASR project to ensure proper design, operation, and any mitigation is identified.

During drought, the primary benefit of an ASR project is to enhance or increase water supply. The stored water can be pumped out of the aquifer (recovered), treated, and utilized as a freshwater supply when needed. While communities can utilize ASR as part of their seasonal or annual supply portfolio, these uses are not part of mitigation activities and do not qualify for funding under the HMA program. At a minimum, assessing the benefits of ASR for drought mitigation requires identifying the increased water supply capacity the ASR project provides in relation to the population supported in a drought during the project's useful life. A recurrence interval for drought periods will need to be identified for use in the FEMA BCA Tool. Estimating the probability of a drought can be difficult due to historical data gaps and variance in annual weather patterns/precipitation. There is not currently a single methodology to establish a recurrence interval for drought. Rather, FEMA encourages communities to use the best available data to document a recurrence interval. In addition to regional or local sources of historical drought periods, federal agency resources that provide drought related resources with information that could support a recurrence interval are discussed in more detail in **Section 3** and **Section 4**.

Section 3

Methodology for ASR BCA

This section discusses a methodology for conducting a system-specific BCA for an ASR project intended for drought mitigation. A full BCA evaluating drought risk, damages, and mitigation should incorporate the probability of a drought occurring (i.e., recurrence interval) coupled with a system-specific analysis of the damages associated with a given drought, both pre- and post-mitigation. One key underlying assumption is that quantified parameters should only be related to drought mitigation. Though portions of an ASR project (new or expanded) may be used for day-to-day or seasonal supply, the sole focus of this BCA methodology is mitigation of drought impacts and associated damages.

This methodology does not replace detailed, system-specific water resources analysis. Instead, it builds upon such an analysis to provide municipal planners (and FEMA) with a high-level tool that assesses the cost effectiveness of designing, constructing, and operating an ASR project. Proper execution of this BCA methodology requires supporting analysis and documentation from a Professional Engineer, Professional Geologist, or similarly qualified water resource professional.

A typical supporting analysis should include the following:

- Potable water demand estimates
  - Normal conditions (no drought)
  - Drought conditions (if unconstrained, demands tend to increase with severity)
- System-specific supply yield analysis
  - Pre-mitigation – without ASR project
  - Post-mitigation – with ASR project

Each municipal water supply system has a unique set of constraints that impacts system yield. This includes the legal and administrative aspects of water resources management, infrastructure capacity, and supply side hydrology. Utilization of system-specific input data is discussed in more detail in **Section 4**.

3.1 Evaluating Pre-mitigation Damages

Pre-mitigation damages due to drought are estimated, largely, by the direct economic impact of loss of water service. FEMA typically analyzes loss of function impacts to water supply assuming a binary “on/off” switch of potable water services provided by a municipality. For example, an emergency shut down of water services due to flood damage. However, this approach is not applicable to drought impacts, as they are not binary; therefore, an “on/off” assumption does not suit assessment of damages due to drought. As a result, a slightly modified approach has been developed and is described below.

The following equation takes drought's non-binary nature into account when estimating pre-mitigation damages due to drought (see *DLF and DOI* terms). Additional explanations for parameters and the proposed methodology are provided in the subsections that follow.

$$\boldsymbol{PreDmg} = \boldsymbol{P} \times (\boldsymbol{LWS} \times \boldsymbol{DLF_{pre}}) \times \boldsymbol{DOI_{pre}}$$

Where,

PreDmg = pre-mitigation damages due to drought, $US

P = population impacted by drought and served by ASR project

LWS = economic value of loss of water service ($US), per person per day.

DLF_{pre} *= drought loss factor, a system-specific adjustment of LWS due to the typical tiered reduction of potable water service under pre-mitigation drought conditions, unitless*

DOI_{pre} *= system specific duration of impact from pre-mitigation drought conditions, days*

Population (P)

The economic value of loss of water (i.e., damages) is dependent upon the number of people impacted by a drought. *Population* as it relates to this methodology is defined by the population that is both impacted by drought and that would benefit from the ASR project under consideration.

Economic Value of Loss of Water Service (LWS)

The current economic value of loss of water service used by FEMA is $103 per capita per day (FEMA, 2011). This value assumes complete loss of service (i.e., "on/off").

Drought Loss Factor (DLF)

Under drought conditions, there is rarely a complete loss of potable water service. Instead, potable water demand is gradually reduced through implementation of drought management strategies such as water use restrictions or rationing for non-essential uses. As a drought progresses in duration and/or severity, the types and magnitude of water use impacted by drought management policies typically increase (i.e., more water users/uses fall under demand management practices). The reduction in demand from implementation of demand management strategies is intended to keep a system's demand from exceeding the system's supply yield; however, this reduction in demand impacts the local and regional economy. In addition, this tiered-reduction of demand, versus an "on/off" loss of water service, must be considered when assessing damages due to drought. To do so, a "loss factor," or *DLF*, is applied to the *LWS* term.

The *DLF* for pre-mitigation drought conditions is defined by the below equation. Inputs for this equation should be determined based on a system-specific, hydrologic analysis and associated ASR feasibility study (see Section 4 for more detail on input requirements). **Figure 3-1** illustrates the parameters associated with *DLF*. Note, *DLF* should be calculated based on the *DOI* of a given drought (the *DOI* term is described in more detail below).

$$DLF = \frac{Drought\ Loss}{Potable\ Water\ Demand}$$

Where,

DLF = pre-mitigation drought loss factor, unitless

Drought Loss = demand not met due to drought conditions (supply constrained), million gallons

Potable Water Demand = potable water demand during drought (supply unconstrained), million gallons.

DLF is system-specific by nature, and the determination of this parameter can range from a general estimate based on annual production values to a detailed assessment of a municipality's drought resiliency.

At a minimum, a municipality should estimate *DLF* at an annual level. In other words, the ratio of potable water production during a drought year compared to an average or "normal," non-drought year should be determined. More in-depth analyses are preferred and are likely commonplace among municipalities considering drought mitigation through ASR. It is not uncommon when assessing the feasibility of an ASR project for a municipality to approximate system supply yield under varying hydrologic conditions using sophistical computer models.

DLF is by nature associated with a recurrence interval (*RI*) for a given drought. Incorporation of drought *RI*s in this BCA methodology is described in **Section 4.1**.

<u>*Duration of Impact (DOI)*</u>

The economic value of loss of water is also dependent upon the duration of a drought's impact on a municipality. The *DOI* is different than the duration of a drought in that impacts of a drought may not affect the supply for a municipal water system immediately. Similarly, impacts of drought may be experienced by a municipal water supply system for a time after climatic and hydrologic drought conditions conclude. This is largely dependent upon the supply portfolio of a municipality and how quickly this portfolio returns to "normal" conditions. *DOI* is defined as the length of time that a municipality experiences a measurable water shortage due to drought. **Figure 3-1** provides an illustration of *DOI* as it relates to this methodology.

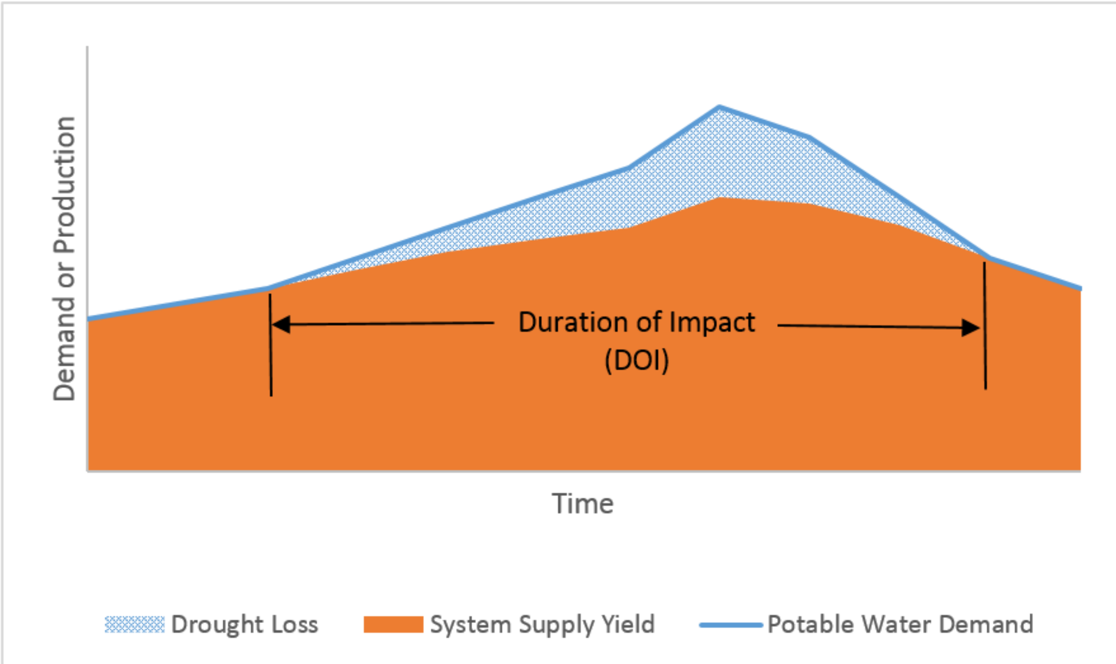

Figure 3-1: Drought Loss Factor

Similar to *DLF*, *DOI* is by nature associated with a drought *RI*. Incorporation of drought *RI*s in this BCA methodology are described in **Section 4.1**.

3.2 Evaluating Post-mitigation Damages

In terms of approach, post-mitigation damages (*PostDmg*) are nearly identical to the *PreDmg* calculations discussed in **Section 3.1**. The following equation is used to estimate post-mitigation damages due to drought.

$$\boldsymbol{PostDmg} = \boldsymbol{P} \times (\boldsymbol{LWS} \times \boldsymbol{DLF_{post}}) \times \boldsymbol{DOI_{post}}$$

Where,

PostDmg = post-mitigation damages due to drought, $US

P = population impacted by drought and served by ASR project

LWS = economic value of loss of water service ($US), per person per day.

DLF_{post} *= drought loss factor, a system specific adjustment of LWS due to the typical tiered reduction of potable water service under drought conditions, unitless*

DOI_{post} *= system specific duration of impact from post-mitigation drought conditions, days*

The difference between *PostDmg* and *PreDmg* is determined by the magnitude of the *DLF* and *DOI* terms; all other independent variables remain the same. After implementation of an ASR project, there is expected to be both a decrease in the loss due to drought (*DLF*) and the duration of the impact due to drought (*DOI*). The difference between *PostDmg* and *PreDmg* defines the damages avoided as a result of ASR implementation. This concept is illustrated in **Figure 3-2**. Full drought mitigation from ASR implementation would result in *PostDmg* being zero (i.e., both DLF_{post} and DOI_{post} equaling zero).

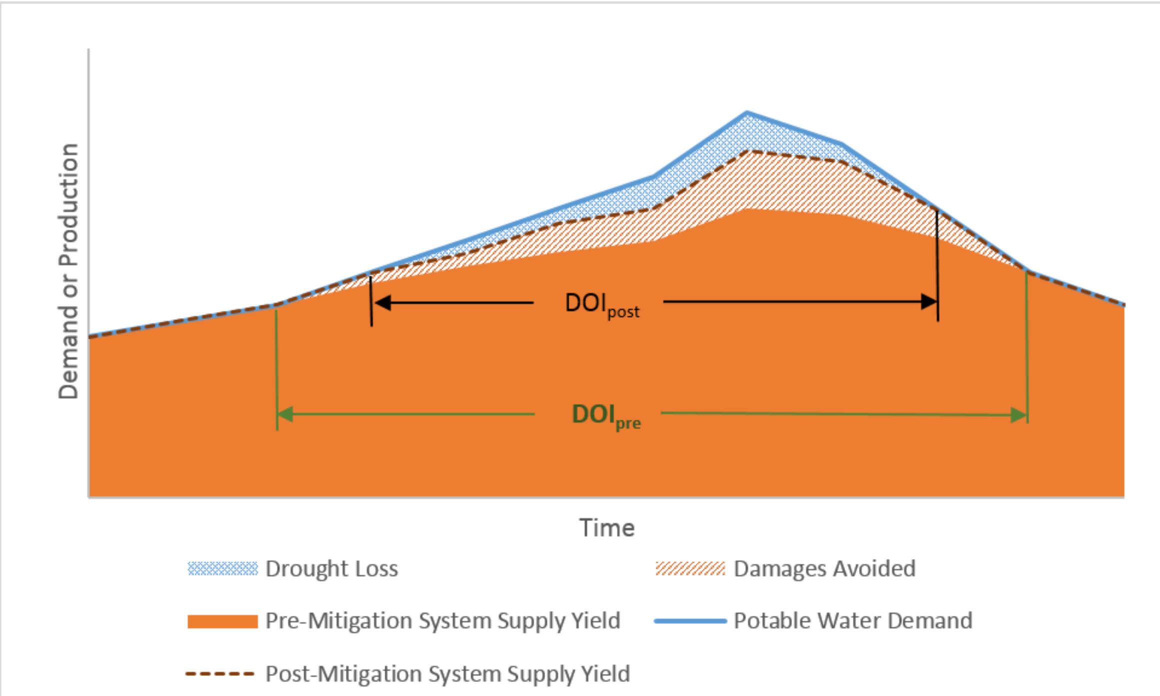

Figure 3-2: Post-mitigation Drought Loss

Section 4 discusses input requirements and how to implement this methodology using the ASR BCA Tool and FEMA BCA Tool v5.2.

Section 4

Application of ASR BCA Tool

This section focuses on implementation of the methodology discussed in Section 3.0. It is presented in a "how to" manner and is intended to quickly assist users with navigating and using the Microsoft Excel based tool ASR BCA Tool.

4.1 How to Apply ASR BCA Tool

The following are steps required to utilize the ASR BCA Tool. Once all user input is provided, the ASR BCA Tool estimates pre- and post-mitigation damages, which serves as direct input to the FEMA BCA Tool. As noted in Section 3, one key underlying assumption is that quantified parameters should only be related to drought mitigation. Though portions of an ASR project (new or expanded) may be used for day-to-day or seasonal supply the sole focus of this BCA methodology is mitigation of drought impacts and associated damages. Note, the majority of input data for the ASR BCA Tool serves as a direct input for the BCA and resulting benefit-cost ratio (BCR) calculations; however, some of the required input will be used as secondary, or complimentary, information by FEMA during the application review process and does not directly impact the BCA or BCR calculations. In addition, the subapplicant is encouraged to submit supplemental documentation for ASR BCA Tool input parameters. Examples of supplemental documentation include memorandum and reports prepared by a licensed Professional Engineer and/or Professional Geologist.

Step 1: Enter General Information

Step 1 in the ASR BCA Tool requires the user to input general information related to the beneficiaries of the ASR project. Specifically, location (city and state), population, and average water use are required.

- *Population* is defined by the population that is both impacted by drought and that would benefit from the ASR project under consideration.
- *Average water use rate* (gallons per capita per day) is defined as the total annual production (in gallons) divided by *population* divided by 365 days under normal, non-drought conditions.

Figure 4-1 below shows an example input for Step 1 for the hypothetical city of Dry Spell, CA. The community of Dry Spell has an existing population of 75,000 people and a corresponding average water use rate of 170 gallons per capita per day. For *population* and *average water use*, the most current year where data are available should be used.

Step 1

General Information

City:	Dry Spell
State:	CA
	Existing
Population Served by Project (*P*):	75,000
Average water use rate (gallons per capita per day)	170

Figure 4-1: Step 1 – General Information User Input

Step 2: Enter Project and Cost Information

Step 2 in the ASR BCA Tool requires the user to input specific information related to infrastructure capacity and cost. These inputs should, at a minimum, be based on a feasibility level assessment of the proposed ASR project performed by a licensed Professional Engineer, Professional Geologist, or similarly qualified professional. It is recommended that supplemental documentation for this input data be provided to FEMA for consideration during application review.

- *Maximum volumetric pumping rate* is related to the production pumping rate (not injection) that delivers stored water for drought mitigating purposes.
- *Average depth to recoverable water* defines the typical depth that stored water must be pumped from during production.
- *Estimated capital cost* should include fixed, one-time implementation costs such as land acquisition, feasibility analysis, design, permitting, construction labor and materials (e.g., piping, pumps, instrumentation), construction oversight, and other miscellaneous costs. *Estimated capital cost* should be provided in present value dollars (US).
- *Annual operations and maintenance costs* should include labor, electricity, consulting services, regulatory testing, maintenance, treatment, raw water, and other miscellaneous costs. Note, operation and maintenance (O&M) costs are not eligible for FEMA funds; however, O&M estimates are required to be included for the purposes of performing a full BCA. *Annual operations and maintenance costs* should be provided in present value dollars (US).
- *Useful life* for an ASR project is assumed to be 30 years. Altering the *useful life* default value of 30 years requires the subapplicant to provide sufficient documentation and sound reasoning.
- *Annualized cost* is calculated based on FEMA's standard approach, assuming a discount rate of 7 percent.

Figure 4-2 below illustrates an example Step 2 input for Dry Spell, CA.

Step 2	
Project and Cost Information	
Maximum Volumetric Pumping Rate (million gallons per day):	5
Average depth to recoverable water (feet)	225
Esimtated Capital Cost of ASR Project (Present Value $US)	$ 3,000,000
Annual Operations and Maintenance Cost (Present Value $US)	$ 100,000
Useful Life	**30**
Annualized Cost	**$ 4,240,904**

Figure 4-2: Step 2 – Project and Cost Information User Input

Step 3: Enter ASR Project Drought and Mitigation Information

Step 3 in the ASR BCA Tool requires the user to input information related to drought impacts, pre- and post-mitigation. These inputs should, at a minimum, be based on a feasibility level assessment of the proposed ASR project performed by a licensed Professional Engineer, Professional Geologist, or similarly qualified professional. It is recommended that supplemental documentation for this input data be provided to FEMA for consideration during application review.

- *Unconstrained potable water demand (million gallons per day [mgd])* is defined as the unconstrained, average potable water demand for a municipal water system considering the specified *RI* and *DOI* of a drought. If unconstrained by supply, municipal demands tend to increase with the severity of drought. This input parameter is typical of a system-specific analysis.
- *Pre- and post-mitigation system supply yield (mgd)* is defined as the dependable supply available from a municipality's water supply system under a defined hydrologic sequence of inflows (adapted from Loucks et al. 2005). The definition of 'dependable' supply will vary by subapplicant based on such factors as overall system storage capacity, legal seniority (as is the case under the Prior Appropriation Doctrine), community/utility risk tolerance, and other quantitative and qualitative considerations that are not appropriate for pre-calculation within the ASR BCA Tool. This input parameter is typical of a system-specific analysis, and it is recommended that supplemental documentation for this input data be provided to FEMA for consideration during application review.
- *Pre- and post-duration of impact* (DOI_{pre}, DOI_{post} days) are described in detail in **Section 3**. This input parameter is typical of a system-specific analysis.
- *Pre- and post-drought loss factor* (DLF_{pre}, DLF_{post}, unitless) is calculated within the tool based on the methodology and equations detailed in **Section 3**.
- *Average yield of ASR project* (mgd) for a given *RI* is calculated within the tool using the below equation. The yield is an estimated average and is expected to be less than the maximum volumetric pumping rate defined in Step 2. This parameter is not used directly in

calculating the BCA or BCR but is instead considered complimentary data for FEMA to consider during application review.

$$\textbf{Average Yield of ASR Project} = SSY_{post} - SSY_{pre}$$

Where,

SSY_{post} = *Post-mitigation system supply yield* (described above)[mgd]

SSY_{pre} = *Post-mitigation system supply yield* (described above)[mgd]

Drought Recurrence Intervals

It is preferred that *Unconstrained Potable Water Demand, SSY, and DOI* be calculated across multiple *RIs* of varying magnitudes (i.e., 25, 50, and 100 year). At a minimum, a single *RI* is required to execute the proposed methodology. Note, the standard approach adopted by FEMA for calculating annualized damages for pre- and post-mitigation conditions as part of a BCA is sensitive to both the *RI* magnitude and the number of *RI*s input by the user. The recurrence of drought is very complex, and there are many variables to be understood in predicting drought. Historically, a recurrence interval has been determined by calculating frequency of occurrence using many years of past data and assuming that the past was a good predictor of future conditions. However, in more recent times, a slightly better understanding about natural and anthropogenic global warming has altered this paradigm. As a result, it is now understood that the future recurrence of extreme weather conditions, such as drought intensity and occurrence, cannot be based in full on historical data.

Based on current FEMA BCA guidance and practices, to evaluate a project that reduces the impacts of drought, it would be necessary to determine the recurrence interval associated with the severity of scenario drought events. Establishing a traditional recurrence interval for drought may be difficult, the subapplicant should use the best available data and methodology deemed appropriate by a licensed Professional Engineer, Professional Geologist, or similarly qualified professional.

In addition to professional services there are numerous federal, state, and local resources available to subapplicants that can assist in selecting and evaluating drought impacts. A sample list of resources is provided below.

- *U.S. Drought Portal* – http://www.drought.gov
- *Drought Risk Atlas* - http://droughtatlas.unl.edu/Data.aspx
- *U.S. Bureau of Reclamation Drought Response Program* - http://www.usbr.gov/drought/

Figure 4-3 below illustrates an example Step 3 input for Dry Spell, CA.

Step 3

ASR Project Drought and Mitigation Information

Drought Recurrence Interval (years)	25	50	100	
Unconstrained Potable Water Demand (million gallons per day [mgd])	13.1	13.8	14.4	
Pre-mitigation System Supply Yield (SSY_{pre}, mgd)	12.5	11.7	10.8	
Pre-mitigation Duration of Impact (DOI_{pre}, days)	30	45	60	
Pre-mitigation Conditions % of Unmet Demand (DLF_{pre}, %)	5%	15%	25%	0%
Post-mitigation System Supply Yield (SSY_{post}, mgd)	13.1	12.8	12.3	
Post-mitigation Duration of Impact (DOI_{post}, days)	0	35	45	
Post-mitigation Conditions % of Unmet Demand (DLF_{post}, %)	0%	7%	15%	0%
Average Yield of ASR Project (mgd)	0.66	1.10	1.50	-

Figure 4-3: Step 3 – ASR Project Drought and Mitigation Information User Input

Step 4: ASR BCA Output

Step 4 does not require any user input into the ASR BCA Tool, instead the ASR BCA Tool calculates the *PreDmg* and *PostDmg* terms based on the approach outlined in **Section 3.1** and **Section 3.2**, respectively. The applicant should use the output values from the ASR BCA Tool to enter into the FEMA BCA Tool v5.2. **Figure 4-4** below illustrates an example Step 4 output for Dry Spell, CA.

Step 4

ASR BCA Module Output

Drought Recurrence Interval (years)	25	50	100	
Pre-mitigation Damages (*PreDmg*)	$ 11,167,343	$ 52,899,457	$ 115,875,000	$ -
Post-mitigation Damages *(PostDmg*)	$ -	$ 19,592,391	$ 50,695,313	$ -

Figure 4-4: Step 4 – ASR BCA Tool Output

Section 5

Conclusion

The methodology and instruction for the ASR BCA tool presented in this report were developed to provide an estimation of the damages avoided due to drought as a result of mitigation through ASR. Although use in other planning initiatives may be appropriate, this methodology is not intended to be used for design purposes but instead is focused on the BCA application. Due to the complex and unique nature of municipal water supply analysis, this high-level analysis has been simplified greatly through the use of assumptions based on engineering judgement. Additionally, this methodology does not replace detailed water resources analysis, but instead, builds upon such an analysis to provide municipal planners (and FEMA) with a high-level tool that assesses the cost effectiveness of an ASR project. It is expected that execution of this BCA methodology will require supporting analysis and documentation by a Professional Engineer, Professional Geologist, or similarly skilled individual(s). Nevertheless, the proposed methodology presents a methodology for subapplicants to evaluate the cost effectiveness of ASR projects for the purpose of seeking FEMA HMA funded mitigation grants.

Section 6

References and Resources

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