CEE 5460 – David Rosenberg

Reservoir Operations Modeling and Yield-Reliability

Learning Objectives

1. **Define** water availability.
2. **Characterize** Guide Curve operation and **relate** reservoir release to available water.
3. **Calculate** reservoir releases given a time series of inflows and delivery targets.
4. **Construct** a release - reliability plot.
5. **Determine** firm yield

Problem setup

- You manage a water utility
- Utility uses an upstream reservoir to supply water to irrigators
- Water quality and quantity concerns
- Single purpose reservoir (no other demands, environmental, or recreational)
- Assume insufficient deliveries result in some negative consequence (example, reduced crop yield, crop loss, etc…)
- Irrigators want to know how much water can the reservoir supply?
- Schematic of problem:

1. Defining Water Availability

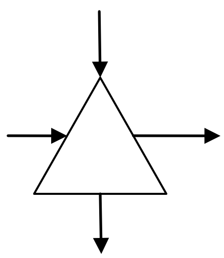
- Water availability is the “maximum amount of water that can

- What does availability depend upon?

- More components mean more complexity.

2. Introducing Reservoir Zones (Pools) and Guide Curve Operation

- The "Guide Curve" is the
  - When storage is <u>above</u> the Guide Curve
  - When storage is <u>below</u> the Guide Curve
- Divides the reservoir storage into pools or zones (see Slide 1)
- Is the "guide" for reservoir operations in the Water Evaluation and Planning (WEAP) model.
- Guide curve is a release rule model – release is a function of available water, storage capacity, the guide curve storage level, and the delivery target.
- A highly simplified system and schematic:



-
- reservoir with a water delivery target.
- are fixed, known volumes
- are known
- Groundwater and seepage effects are considered negligible
- VARIABLE DEFINITIONS:

I_t =

P_t =

M_t =

R_t =

D_t =

AW_t =

S_t =

S_t' =

ΔS_t = Change storage in the reservoir in time *t*

DP =

B =

G =

All variables are in units of except DP, B, G, S_t, and S_t', which have units of

3B) Equations

- Storage continuity

ΔS_t = Change in reservoir storage is

ΔS_t =

S_t' =

S_t' =

- Assume that there is no change in storage between the end of the current time period and the start of the next one, so:

- Available water is the maximum volume of water that can be released from the reservoir during time *t*.

  How do we derive the formula for Available Water?

  1. Assume the maximum release, , will completely empty the reservoir.
     S_t' =
     S_t' =

  2. Rearrange, and for this case, and this case only, because you released everything and drained the reservoir:

     $R_{max\ t}$ =
     $AW_t = R_{max\ t}$ =

3C) Guide Curve Release Rule

- Now let’s specify the Guide Curve release rule.
- Qualitatively it says:
    - When reservoir storage is below the guide curve, release as much water as possible to
    - When reservoir storage is above the guide curve, release
    - Spill is a release
- Graph of Guide Curve Release Rule (see Slide 2):

Mathematically:

- R_t =

- Tabular view of the Guide Curve rule.

Condition	Release	Delivery Target Satisfied?	Description
$AW_t < DP$			
$DP < AW_t \leq B_t$			
$B_t < AW_t \leq G + D_t$			
$G + D_t < AW_t$			

3. Example Calculations

- Let's do a simple example. The delivery target is fixed, precipitation and misc losses are known. The Dead Pool, Buffer, and Guide Curve levels are specified and the reservoir starting storage is the guide curve level.

Time Step	D_t	I_t	P_t	M_t	DP_t	B_t	G_t	S_t	AW_t	R_t	S_t'
1	100	160	5	20	15	120	230	230			
2	100	10	5	30	15	120	230				
3	100	30	5	20	15	120	230				
4	100	20	10	30	15	120	230				
5	100	10	5	20	15	120	230				
6	100	125	15	20	15	120	230				

$AW_1 =$

$D_1 + C =$

$R_1 =$

$S_1' =$

$S_2 =$

$AW_2 =$

$D_2 =$

$R_2 =$

S_2’ =

S_3 =

AW_3 =

D_3 =

R_3 =

S_3’ =

S_4 =

AW_4 =

AW_4 =

R_4 =

S_4’ =

$AW_5 = 155$; $R_5 = D_5 = 100$; S_5’ = 55

$S_6 = 55$; $AW_6 = 160$; $R_6 = D_6 = 100$; S_6’ = 60

4. Construct the Release - Reliability curve

- This exceedance curve describes the probability (reliability) that we’ll be able to meet or exceed a specified release volume. It’s also called a Yield-Reliability curve.
- Visually represents the range of possible deliveries from the reservoir and the probability that the reservoir can meet or exceed each release value.
- For example:

- Non-exceedence = 1 - Exceedence
- In the example we calculated a range of releases from our reservoir; six in total.

- Sort those six values from biggest to smallest; then assign a probability plotting position.

- Can use the Weibull plotting position formula:

  P =

- This formula will not give a zero or a one hundred percent probability. Recall that the release-reliability curve is based on the known historical record. It is possible that in the future there will be a wetter or drier period. So you wouldn't want to give the false impression that we know the exact maximum and minimum value this reservoir system could provide.
- Let's apply it.

Time Step	**R_t**
1	
2	
3	
4	
5	100
6	100

R_t	**Rank**	**Plotting Position**
	1	1/7 = 0.14
	2	2/7 = 0.29
	3	3/7 = 0.43
	4	4/7 = 0.57
	5	5/7 = 0.71
	6	6/7 = 0.86

See Slide #3

Reading the plot: There is a 71% chance that

A yield reliability curve is helpful to managers because it visually depicts shortages and surpluses and their associated frequency.

5. Determining Firm Yield

- Firm Yield is the

- It is a single value

- In the previous example, Firm Yield =

Conclusions

- Today we defined water availability.
- We also

- Showed how to

- We also constructed release-reliability charts which provide water managers with information regarding a range of releases that can be expected from the reservoir and the probability of any release within that range.
- Determined the firm yield of the system which is

- Overall, tools like release-reliability curves and reservoir operations models help water planners better manage their system