sustainability

MDPI

# Supplementary Material

## S1 – Aggregation of Small Reservoirs into "Ponds" in SWAT Model

In the modeling of High-density Reservoir Network (HdRN), multiple small reservoirs can share the same sub-basin. In this case, there are two possible arrangements to be evaluated in the arrangement of small reservoirs in the sub-basins: the cascade arrangement and the parallel arrangement. In the cascade arrangement two or more reservoirs are located one behind the other on the same river reach, while in the parallel arrangement each reservoir is located on a separate river branch of the same order. In the cascade arrangement, the filling of a downstream reservoir depends on the amount of water held up by reservoirs further upstream and thus the cumulative effect on the storage capacities and drainage areas of all upstream reservoirs. On the other side, in the parallel arrangement, the filling and spilling processes are independent in each small reservoir. Figure S1 represents both arrangements.

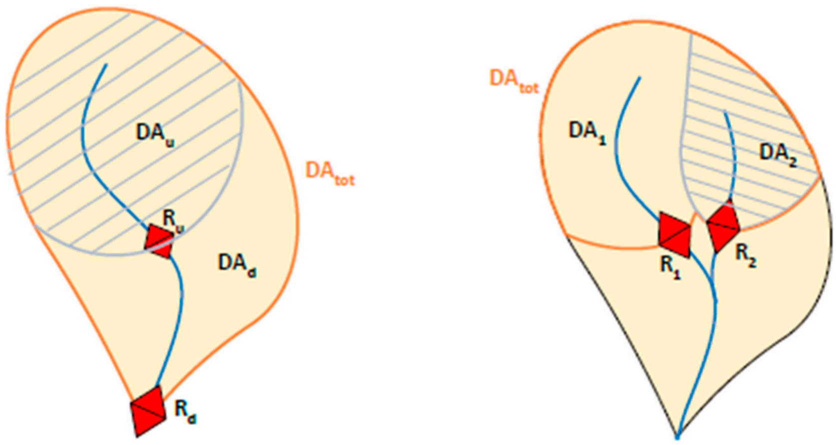


**Figure S1.** Schematic illustration of a sub-basin containing two small reservoirs configured in a cascade (left) and a parallel (right) arrangement. $DA_{tot}$: drainage area of the aggregated pond defining the total drainage fraction of the sub-basin; $R_d/R_1$ (red squares): downstream/first reservoir; $R_u/R_2$ (red squares): upstream/second reservoir; $DA_d/DA_1$ (not hatched): drainage area of downstream/first reservoir; $DA_u/DA_2$ (hatched in grey): drainage area of upstream/second reservoir; Blue line: river reaches.

A limitation to represent small reservoirs in SWAT is that the model allows only one single "pond" to be allocated to each sub-basin. It is common that many sub-basins ended up containing multiple small reservoirs after the watershed delineation. So, it is necessary to aggregate the small reservoirs into one "pond" in the model to represent the reservoir network. Based on the arrangement of small reservoirs and their drainage areas, Udinart et al. [1] developed certain calculation rules that were applied for the determination of the aggregated reservoir volume. The assumptions used in the aggregation methodology of the small reservoirs were:

1. Drainage areas of downstream reservoirs were kept fixed, while the volumes were reduced if necessary.
2. Only a fraction of the sub-basin contributes to runoff production that does not drain into any reservoir.
3. In the case that a pond is located directly at the outlet, no outflow from the sub-basin will occur until the storage capacity of the aggregated pond is exceeded.

Two extreme states may be distinguished regarding the storage effect:

1. The first state occurs when the entire amount of generated runoff in the system is stored. Thhis threshold is the effective capacity of the small reservoir network. Only if a certain threshold water volume is exceeded the system spills. The effective capacity of the reservoir network determines whether it spills.
2. The second state occurs after some consecutive rainy days and after the full saturation of the system. At this point, the system only damps the outflow hydrograph, releasing the amount of water above the total storage capacity of the system. The total storage capacity determines how much water is spilled.
3. To simulate a storage effect that will match the one in reality on average, it was set the equivalent storage capacity of the lumped pond to a value in between effective capacity and total storage capacity.

Considering the cascade arrangement, if the relation of capacity to drainage area of an upstream reservoir is equal to or smaller than that of the downstream reservoir the upper dam will spill first. Hence, the equivalent storage capacity of the system amounts to the total capacity, the sum of both. In the case that this ratio is higher for the upstream reservoir, the downstream reservoir will spill first. In this case, the equivalent capacity is calculated as the sum between the full capacity of the reservoir with the larger specific drainage area and the other capacity reduced by the fraction of the two drainage areas. The following equations represent these processes.

$$if\ \frac{V(R_u)}{DA_u} \leq \frac{V(R_d)}{DA_d}: \tag{S1}$$

$$V_{eq} = V(R_u) + V(R_d) \tag{S2}$$

$$if\ \frac{V(R_u)}{DA_u} > \frac{V(R_d)}{DA_d}:$$

$$if\ DA_u > DA_d\text{: } V_{eq} = V(R_u) + \frac{DA_d}{DA_u} \cdot V(R_d) \tag{S3}$$

$$if\ DA_u < DA_d\text{: } V_{eq} = V(R_d) + \frac{DA_u}{DA_d} \cdot V(R_u) \tag{S4}$$

- $Veq$: equivalent storage capacity of aggregated pond
- $V(R_u)$: storage capacity of upstream reservoir
- $V(R_d)$: storage capacity of downstream reservoir
- $DA_u$: drainage area of upstream reservoir
- $DA_d$: drainage area of downstream reservoir

Considering the parallel arrangement of small reservoirs in the same sub-basin, if the relation of capacity to drainage area of two reservoirs is equal both will spill at the same time. Hence, the equivalent storage capacity of the system amounts to the total capacity, the sum of both. For the case that this relation is smaller for one of the reservoirs, this dam will spill before the other one. In this case, the equivalent capacity is calculated as the sum of the full capacity of the reservoir with the larger specific drainage area and the other capacity reduced by the fraction of the two drainage areas. The following equations represent these processes.

$$if\ \frac{V(R_1)}{DA_1} \approx \frac{V(R_2)}{DA_2}: \tag{S5}$$

$$V_{eq} = V(R_1) + V(R_2) \tag{S6}$$

$$if\ \frac{V(R_1)}{DA_1} \neq \frac{V(R_2)}{DA_2}: \tag{S7}$$

$$if\ DA_1 > DA_2:\ V_{eq} = V(R_1) + \frac{DA_2}{DA_1} \cdot V(R_2) \tag{S8}$$

$$if\ DA_1 < DA_2:\ V_{eq} = V(R_2) + \frac{DA_1}{DA_2} \cdot V(R_1) \tag{S9}$$

- $Veq$: equivalent storage capacity of aggregated pond
- $V(R_1)$: storage capacity of first reservoir
- $V(R_2)$: storage capacity of second reservoir
- $DA_1$: drainage area of first reservoir
- $DA_2$: drainage area of second reservoir

In case that multiple small reservoirs are arranged in the same configuration or that the two arrangements are combined in one sub-basin, it was started with the most upstream reservoirs. Their volumes were aggregated according to the respective rule, then this intermediate equivalent volume was again lumped with the small reservoir further downstream and so on. A detailed description of this methodology can be found in Rabelo et al. [1].

**Table S1.** Parameterization of reservoirs (water impoundments implemented into the model as reservoirs). Reservoir numbers and sub-basin numbers correspond to the IDs given automatically in ArcGIS. Abbreviations B., dC., and PP. stand for Benguê, Do Coronel, Poço da Pedra, respectively.

| SWAT PARAMETER | | MORES | IYRES | RES_ESA [10000 m²] | RES_EVOL [10000 m³] | RES_PSA [10000 m²] | RES_PVOL [10000 m³] | RES_VOL [10000 m³] | RES_K [mm/h] | EVRSV | IRESCO | RES_TARG [10000 m³] | NDTARGR [d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXPLANATION | | Month, in which reservoir became operational | Year, in which reservoir became operational | Surface area when reservoir filled to emergency spillway | Storage volume when reservoir filled to emergency spillway | Surface area when reservoir filled to principle spillway | Storage volume when reservoir filled to principle spillway | Initial reservoir storage volume | Hydraulic conductivity of reservoir bottom | Lake evaporation coefficient | Reservoir outflow simulation code | Manually set target volume (equal for each months) | No. of days to reach target storage from current reservoir storage |
| RES-NO. | SB-No. | | | | | | | | | | | | |
| **2 (B.)** | 7 | 8 | 2000 | 438.00 | 2937.00 | 348.00 | 1956.00 | 85.80 | 0.0 | 1 | 2 | 1956.00 | 1.04 |
| **1 (DC.)** | 70 | 1 | 1979 | 100.00 | 300.00 | 50.00 | 177.00 | 46.80 | 0.0 | 1 | 2 | 177.00 | 1.08 |
| **0 (PP.)** | 108 | 11 | 1979 | 1639.00 | 14696.00 | 832.00 | 5200.00 | 1698.00 | 0.0 | 1 | 2 | 5200.00 | 2.25 |
| **13** | 31 | 11 | 1994 | 22.56 | 66.91 | 15.89 | 38.19 | 0.00 | 0.1 | 1 | 2 | 38.19 | 1.01 |
| **17** | 57 | 11 | 2003 | 40.10 | 107.62 | 26.89 | 57.67 | 0.00 | 0.1 | 1 | 2 | 57.67 | 1.00 |
| **19** | 91 | 11 | 1999 | 23.13 | 63.44 | 15.77 | 34.66 | 0.00 | 0.1 | 1 | 2 | 34.66 | 1.00 |
| **24** | 54 | 1 | 1991 | 7.47 | 13.66 | 4.08 | 5.07 | 0.00 | 0.1 | 1 | 2 | 5.07 | 1.00 |
| **30** | 18 | 1 | 1979 | 21.93 | 62.36 | 15.17 | 34.66 | 3.47 | 0.1 | 1 | 2 | 34.66 | 1.00 |
| **32** | 39 | 1 | 1979 | 12.39 | 32.56 | 8.31 | 17.10 | 1.71 | 0.1 | 1 | 2 | 17.10 | 1.00 |
| **34** | 96 | 1 | 1979 | 10.96 | 24.59 | 6.82 | 11.34 | 1.13 | 0.1 | 1 | 2 | 11.34 | 1.00 |
| **46** | 118 | 1 | 1979 | 89.26 | 307.50 | 64.40 | 192.83 | 38.57 | 0.1 | 1 | 2 | 192.83 | 1.14 |
| **90** | 78 | 1 | 1979 | 14.75 | 37.03 | 9.71 | 18.78 | 1.88 | 0.1 | 1 | 2 | 18.78 | 1.00 |
| **123** | 165 | 1 | 1979 | 20.74 | 64.12 | 14.82 | 37.55 | 3.75 | 0.1 | 1 | 2 | 37.55 | 1.00 |
| **128** | 172 | 1 | 1979 | 4.19 | 12.91 | 2.97 | 7.56 | 0.00 | 0.1 | 1 | 2 | 7.56 | 1.00 |
| **146** | 89 | 1 | 1979 | 45.03 | 127.57 | 30.74 | 71.06 | 7.11 | 0.1 | 1 | 2 | 71.06 | 1.05 |
| **197** | 126 | 1 | 1979 | 8.91 | 18.15 | 5.25 | 7.60 | 0.00 | 0.1 | 1 | 2 | 7.60 | 1.00 |
| **203** | 170 | 1 | 1979 | 5.97 | 8.26 | 2.39 | 2.15 | 0.00 | 0.1 | 1 | 2 | 2.15 | 1.00 |

**Table S2.** Parameterization of ponds (water impoundments implemented into the model as ponds). Sub-basin numbers correspond to the IDs given automatically in ArcGIS.

| SB NO. | DRAINAGE FRACTION [-] | VOLUME PRINCIPLE (VPR) [10000 M³] | SURFACE AREA PRINCIPLE (SAPR) [10000 M²] | VOLUME EMERGENCY (VEM) [10000 M³] | SURFACE AREA EMERGENCY (SAEM) [10000 M²] | INITIAL STORAGE [10000 M³] | NDTARG [D] |
|---|---|---|---|---|---|---|---|
| **2** | 0.1407 | 7.5238 | 8.6954 | 19.8279 | 16.2424 | 0 | 1 |
| **3** | 1 | 180.773 | 57.3379 | 245.2304 | 71.9404 | 36 | 1.35 |
| **5** | 0.4696 | 0.8167 | 1.8449 | 4.2163 | 5.1859 | 0 | 1 |
| **6** | 1 | 7.5132 | 9.6866 | 24.3122 | 23.3748 | 0 | 1 |
| **8** | 0.0391 | 3.7472 | 4.8147 | 10.7188 | 9.3316 | 0 | 1.23 |
| **10** | 0.4067 | 4.9495 | 7.3037 | 13.0763 | 15.9801 | 0 | 1 |
| **13** | 1 | 5.1694 | 5.8958 | 13.3848 | 10.7323 | 0 | 1 |
| **19** | 0.1458 | 0.8939 | 2.2837 | 5.4764 | 7.2734 | 0 | 1 |
| **23** | 0.0763 | 0.9053 | 1.9686 | 4.4619 | 5.374 | 0 | 1 |
| **25** | 1 | 1.2363 | 3.0887 | 7.26 | 9.4324 | 0 | 1 |
| **27** | 1 | 1.3203 | 2.4965 | 5.5348 | 6.1549 | 0 | 1 |
| **28** | 0.6053 | 1.5654 | 3.311 | 7.7935 | 9.624 | 0 | 1 |
| **33** | 1 | 0.3281 | 1.0389 | 2.6666 | 3.8864 | 0 | 1 |
| **34** | 0.3461 | 1.0677 | 2.184 | 4.8947 | 5.6966 | 0 | 1 |
| **36** | 0.2796 | 2.7783 | 3.9881 | 8.7843 | 8.2325 | 0 | 1 |
| **40** | 0.2456 | 0.2206 | 0.8092 | 2.2375 | 3.4799 | 0 | 1 |
| **43** | 1 | 2.3644 | 3.6029 | 7.9147 | 7.7095 | 0 | 1 |
| **46** | 0.8 | 0.6155 | 1.2528 | 3.2769 | 4.3561 | 0 | 1 |
| **59** | 0.8349 | 1.3593 | 3.6802 | 9.2813 | 12.9686 | 0 | 1 |
| **60** | 0.1041 | 0.1517 | 0.6393 | 1.9212 | 3.1614 | 0 | 1 |

| SB NO. | DRAINAGE FRACTION [-] | VOLUME PRINCIPLE (VPR) [10000 M³] | SURFACE AREA PRINCIPLE (SAPR) [10000 M²] | VOLUME EMERGENCY (VEM) [10000 M³] | SURFACE AREA EMERGENCY (SAEM) [10000 M²] | INITIAL STORAGE [10000 M³] | NDTARG [D] |
|---|---|---|---|---|---|---|---|
| **61** | 1 | 5.4467 | 7.7014 | 17.1033 | 16.0336 | 0 | 1 |
| **64** | 0.3512 | 13.3103 | 10.6946 | 26.894 | 16.6532 | 1.3 | 1 |
| **65** | 1 | 5.1583 | 6.819 | 15.6876 | 14.6899 | 0 | 1 |
| **69** | 1 | 1.5008 | 4.0274 | 9.7324 | 13.1594 | 0 | 1 |
| **71** | 0.3748 | 1.1897 | 2.5641 | 6.0043 | 7.4319 | 0 | 1 |
| **72** | 0.819 | 1.7086 | 3.3212 | 7.5068 | 8.6277 | 0 | 1 |
| **74** | 0.4773 | 2.6592 | 4.4424 | 10.284 | 9.7641 | 0 | 1.22 |
| **75** | 0.0524 | 0.2017 | 0.8205 | 2.4195 | 3.9328 | 0 | 1 |
| **77** | 0.3162 | 2.9359 | 5.4036 | 12.6029 | 14.5969 | 0 | 1 |
| **79** | 0.2002 | 0.8926 | 2.127 | 4.9608 | 6.3172 | 0 | 1.02 |
| **80** | 0.4298 | 0.2251 | 1.0437 | 3.4006 | 5.8433 | 0 | 1 |
| **81** | 0.8215 | 0.6982 | 1.7436 | 4.1308 | 5.3995 | 0 | 1 |
| **82** | 0.7291 | 0.4968 | 1.5373 | 4.1508 | 6.2157 | 0 | 1 |
| **85** | 1 | 3.6826 | 4.7623 | 10.5934 | 9.2627 | 0 | 1 |
| **87** | 0.4025 | 2.9633 | 5.2069 | 11.8974 | 13.1948 | 0 | 1.05 |
| **88** | 0.95 | 0.7407 | 1.8059 | 4.2567 | 5.5043 | 0 | 1 |
| **90** | 1 | 1.5455 | 3.1587 | 7.5267 | 9.2915 | 0 | 1 |
| **93** | 1 | 7.5586 | 8.8378 | 20.4257 | 17.3195 | 0 | 1.02 |
| **95** | 0.7517 | 0.6823 | 1.6475 | 3.829 | 4.8805 | 0 | 1 |
| **98** | 0.4006 | 1.031 | 2.8662 | 7.3597 | 10.478 | 0 | 1 |
| **99** | 0.1782 | 0.7418 | 2.1364 | 5.2665 | 7.3392 | 0 | 1 |
| **100** | 1 | 29.5171 | 26.1075 | 64.7025 | 45.078 | 2.95 | 1.02 |
| **102** | 1 | 5.2178 | 7.5602 | 16.7197 | 15.8657 | 0 | 1 |
| **106** | 1 | 4.6885 | 5.7291 | 12.9448 | 11.0297 | 0 | 1 |
| **107** | 1 | 16.1602 | 13.5462 | 34.7797 | 24.2638 | 0 | 1 |
| **110** | 0.6358 | 6.8338 | 7.2609 | 17.1445 | 13.7023 | 0 | 1.04 |
| **112** | 0.0922 | 0.3418 | 1.066 | 2.7175 | 3.9329 | 0 | 1 |
| **113** | 0.3669 | 2.3219 | 5.0349 | 11.6349 | 14.25 | 0 | 1 |
| **117** | 0.081 | 4.1549 | 5.797 | 12.799 | 11.7793 | 0 | 1 |
| **119** | 0.1587 | 2.3743 | 4.6125 | 10.3382 | 11.7731 | 0 | 1 |
| **120** | 1 | 6.3861 | 8.8767 | 19.733 | 18.2893 | 0 | 1.05 |
| **122** | 1 | 3.6661 | 6.3311 | 14.2447 | 15.3917 | 0 | 1 |
| **123** | 1 | 4.1293 | 6.2352 | 14.076 | 14.1237 | 0 | 1 |
| **124** | 0.9464 | 2.5164 | 4.4371 | 10.3236 | 11.7177 | 0 | 1 |
| **128** | 0.1765 | 0.3815 | 1.1425 | 2.8614 | 4.0627 | 0 | 1 |
| **131** | 0.1025 | 0.578 | 1.4841 | 3.5123 | 4.6224 | 0 | 1 |
| **132** | 0.191 | 2.0321 | 4.3421 | 9.9109 | 11.9397 | 0 | 1 |
| **134** | 1 | 9.3236 | 13.8683 | 31.2845 | 31.0957 | 0 | 1 |
| **135** | 1 | 31.3789 | 22.0259 | 59.2537 | 34.1384 | 3.14 | 1.02 |
| **137** | 0.2512 | 1.0437 | 2.5996 | 6.1387 | 7.9998 | 0 | 1 |
| **138** | 0.1997 | 0.4126 | 1.2002 | 2.9704 | 4.1595 | 0 | 1 |
| **139** | 1 | 3.279 | 4.4266 | 9.7989 | 8.819 | 0 | 1 |
| **142** | 1 | 3.8062 | 5.6076 | 12.4575 | 12.0347 | 0 | 1 |
| **144** | 0.9 | 0.7818 | 1.7949 | 4.1178 | 5.1092 | 0 | 1 |
| **149** | 0.2237 | 0.1046 | 0.5058 | 1.6715 | 2.8961 | 0 | 1 |
| **150** | 0.5671 | 0.3025 | 0.9872 | 2.5698 | 3.7969 | 0 | 1 |
| **153** | 0.1916 | 25.1365 | 15.9595 | 44.4581 | 22.853 | 2.51 | 1.15 |
| **154** | 0.0536 | 0.0951 | 0.4765 | 1.6162 | 2.8355 | 0 | 1 |
| **157** | 0.1087 | 0.6223 | 1.8313 | 4.6474 | 6.6331 | 0 | 1.05 |
| **159** | 1 | 0.304 | 0.9902 | 2.5753 | 3.802 | 0 | 1 |
| **168** | 0.3333 | 0.7133 | 1.6942 | 3.9201 | 4.9533 | 0 | 1.19 |
| **171** | 0.9508 | 3.1478 | 4.3143 | 9.5366 | 8.6696 | 0 | 1 |
| **173** | 0.1667 | 0.2131 | 0.7918 | 2.2051 | 3.4481 | 0 | 1 |
| **175** | 1 | 2.5427 | 3.7716 | 8.2931 | 7.9395 | 0 | 1 |
| **181** | 1 | 2.6293 | 3.852 | 8.4747 | 8.0486 | 0 | 1 |
| **183** | 0.0633 | 5.2966 | 5.9868 | 13.6159 | 10.8486 | 0 | 1.07 |
| **187** | 0.0855 | 0.3322 | 1.0472 | 2.6822 | 3.9006 | 0 | 1 |
| **193** | 1 | 2.8781 | 4.0776 | 8.9893 | 8.3529 | 0 | 1 |
| **195** | 1 | 1.0286 | 2.1333 | 4.7922 | 5.6212 | 0 | 1 |

**Table S3.** Parameterization of calibrated model: Parameters set for the entire catchment.

| ENTIRE CATCHMENT | |
|---|---|
| **CALIBRATED PARAMETER** | **Calibrated Value** |
| **GW_DELAY** | 12 d and 30 d |
| **CH_K1** | 5 mm/h to 72 mm/h |
| **TRNSRCH** | 0.3 |
| **OV_N** | 0.6 |
| **CN2** | 57.34 to 92 |
| **CH_N1** | 0.065 |
| **CANMX** | 1.5 |

**Table S4.** Parameterization of calibrated model: Parameters set for specific sub-basins of the catchment. Distinction between sub-catchments of two strategic reservoirs and topographic position of sub-basins.

| | SUB-CATCHMENTS | | SPECIFIC SUB-BASINS | | | |
|---|---|---|---|---|---|---|
| **CALIBRATED PARAMETER** | **Poço da Pedra Catchment** | **Benguê Catchment** | **Upstream SB** | **Transition SB/Medium-order Reaches** | **Downstream SB/High-order Reaches** | **Lowlands (incl. Do Coronel Sub-catchment)** |
| | **Calibrated Values** | | | | | |
| **REVAPMN** | 265 | 265 | 265 | 265 | 265 | 265 |
| **GW_REVAP** | 0.15 | 0.15 | 0.25 | 0.15 | 0.1 | 0.25 |
| **GWQMN** | 700 | 700 | 700 | 700 | 700 | 700 |
| **CH_K2** | 25 | 19 | 5 | 20 | 72 | 72 |
| **CH_N2** | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| **SURLAG** | 4 | 4 | 4 | 4 | 4 | 4 |
| **ALPHA_BF** | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| **RCHARG_DP** | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| **ALPHA_BNK** | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |

**Table S5.** Parameterization of calibrated model: Parameters set for specific zones in the catchment. Distinction between soil types.

| | SOIL TYPE | | | | |
|---|---|---|---|---|---|
| **CALIBRATED PARAMETERS** | **Bruno** | **Latosol** | **LitolicosEu** | **Planosolos** | **Podisolico-EqEu** |
| | **Calibrated Values** | | | | |
| **ESCO** | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| **LAT_TTIME** | 0 | 0 | 0 | 0 | 0 |
| **SOL_K** | PTF results* | PTF results* | PTF results* x 0.8 | PTF results* | PTF results* |
| **SOL_AWC** | PTF results* | PTF results* | PTF results* x 1.2 | PTF results* | PTF results* |
| **GW_REVAP** | 0.1 and 0.15 | 0.15 | 0.1, 0.15 and 0.25 | 0.25 | 0.1 and 0.15 |
| **SOL_CRK** | 0.3 | 0.4 | 0.3 | 0.01 | 0.01 |

*PTF results can be found at Rabelo et al. [1].

**Table S6. -** Annual streamflow in m³/s at Malhada Station for each increase in the number of small reservoirs per year of simulation.

| Annual Streamflow [m³/s] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Observed by COGERH | Reference model | Simulation models - Small reservoirs per area of catchment | | | | | | | |
| | | | 0.1/km² | 0.25/km² | 0.5/km² | 0.75/km² | 1.0/km² | 1.5/km² | 2.0/km² | 3.0/km² |
| **1981** | 699.5 | 1828.8 | 1820.8 | 1786.5 | 1739.5 | 1712.3 | 1689.0 | 1661.9 | 1638.2 | 1604.6 |
| **1982** | 204.9 | 275.9 | 274.1 | 268.5 | 261.0 | 256.7 | 253.0 | 248.0 | 244.0 | 237.8 |
| **1983** | 11.9 | 41.6 | 40.9 | 39.0 | 37.3 | 36.4 | 35.7 | 34.5 | 33.6 | 32.6 |
| **1984** | 951.3 | 507.1 | 504.6 | 496.3 | 486.1 | 479.2 | 472.7 | 463.7 | 456.0 | 445.9 |
| **1985** | 5905.2 | 4303.6 | 4295.6 | 4257.2 | 4200.7 | 4155.6 | 4113.5 | 4052.6 | 3990.6 | 3897.3 |
| **1986** | 1791.5 | 1771.4 | 1765.4 | 1753.3 | 1741.2 | 1730.4 | 1722.8 | 1707.4 | 1694.4 | 1673.2 |
| **1987** | 699.8 | 571.4 | 570.6 | 564.4 | 558.2 | 552.5 | 548.5 | 540.2 | 533.8 | 524.6 |
| **1988** | 839.4 | 680.8 | 677.8 | 666.8 | 655.3 | 648.1 | 640.9 | 623.5 | 612.8 | 598.1 |
| **1989** | 3373.2 | 1830.7 | 1827.1 | 1811.3 | 1793.7 | 1783.0 | 1772.3 | 1756.2 | 1736.2 | 1708.3 |
| **1990** | 236.2 | 209.9 | 209.3 | 207.6 | 205.2 | 203.8 | 202.3 | 199.5 | 197.7 | 194.9 |
| **1991** | 52.5 | 8.1 | 7.9 | 7.7 | 7.6 | 7.5 | 7.4 | 7.3 | 7.2 | 7.1 |
| **1992** | 347.7 | 560.3 | 557.3 | 547.8 | 536.0 | 527.4 | 521.4 | 512.8 | 505.8 | 493.3 |
| **1993** | 1.3 | 11.7 | 11.3 | 10.7 | 10.5 | 10.3 | 10.2 | 10.0 | 9.9 | 9.8 |
| **1994** | 73.3 | 154.4 | 152.8 | 149.3 | 145.7 | 142.2 | 139.2 | 136.8 | 133.0 | 128.8 |
| **1995** | 816.0 | 478.8 | 476.1 | 467.8 | 458.6 | 451.4 | 445.1 | 436.6 | 429.5 | 419.4 |
| **1996** | 97.1 | 175.9 | 174.9 | 170.8 | 166.5 | 163.2 | 160.2 | 156.6 | 153.9 | 148.5 |
| **1997** | 1219.2 | 486.0 | 483.5 | 473.1 | 461.5 | 453.5 | 448.1 | 439.8 | 431.6 | 418.0 |
| **1998** | 21.7 | 16.7 | 16.4 | 15.3 | 14.3 | 13.7 | 13.3 | 12.7 | 12.3 | 11.7 |
| **1999** | 115.1 | 154.3 | 153.2 | 148.2 | 140.6 | 134.3 | 130.0 | 124.8 | 122.1 | 118.1 |
| **2000** | 240.4 | 316.8 | 314.4 | 307.5 | 299.9 | 294.0 | 289.9 | 282.3 | 275.5 | 265.4 |
| **2001** | 0.0 | 7.0 | 7.0 | 6.9 | 6.9 | 6.8 | 6.8 | 6.7 | 6.7 | 6.6 |
| **2002** | 288.4 | 369.7 | 367.7 | 360.2 | 351.2 | 346.4 | 341.0 | 333.6 | 327.7 | 321.1 |
| **2003** | 109.1 | 131.5 | 130.2 | 125.8 | 120.5 | 117.2 | 115.5 | 112.2 | 110.2 | 107.1 |
| **2004** | 3741.3 | 4157.2 | 4147.6 | 4112.1 | 4066.7 | 4033.0 | 4006.5 | 3959.5 | 3915.8 | 3841.6 |
| **2005** | 44.7 | 33.9 | 33.0 | 31.2 | 28.9 | 27.5 | 26.2 | 25.1 | 24.4 | 23.8 |
| **2006** | 195.0 | 476.8 | 474.0 | 463.9 | 454.0 | 444.5 | 439.1 | 428.0 | 418.3 | 404.7 |
| **2007** | 454.8 | 814.5 | 810.3 | 799.2 | 784.1 | 774.8 | 767.7 | 755.4 | 743.4 | 726.7 |
| **2008** | 332.9 | 743.9 | 740.1 | 729.7 | 719.4 | 711.1 | 704.8 | 694.5 | 685.4 | 673.4 |
| **2009** | 895.9 | 1334.6 | 1324.2 | 1302.7 | 1276.3 | 1257.6 | 1244.9 | 1220.2 | 1202.2 | 1173.6 |
| **2010** | 38.1 | 130.4 | 129.4 | 123.7 | 118.6 | 116.5 | 115.5 | 113.2 | 110.9 | 107.6 |

**Table S7. -** Percentage of annual streamflow reduction at Malhada Station for each increase in the number of small reservoirs per year of simulation.

| Annual Percentage of Flow Reduction | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Reference model | Simulation models - Small reservoirs per area of catchment | | | | | | | |
| | | 0.1/km² | 0.25/km² | 0.5/km² | 0.75/km² | 1.0/km² | 1.5/km² | 2.0/km² | 3.0/km² |
| **1981** | - | −0.4% | −2.3% | −4.9% | −6.4% | −7.6% | −9.1% | −10.4% | −12.3% |
| **1982** | - | −0.6% | −2.7% | −5.4% | −6.9% | −8.3% | −10.1% | −11.6% | −13.8% |
| **1983** | - | −1.6% | −6.2% | −10.4% | −12.6% | −14.2% | −17.1% | −19.2% | −21.5% |
| **1984** | - | −0.5% | −2.1% | −4.1% | −5.5% | −6.8% | −8.6% | −10.1% | −12.1% |
| **1985** | - | −0.2% | −1.1% | −2.4% | −3.4% | −4.4% | −5.8% | −7.3% | −9.4% |
| **1986** | - | −0.3% | −1.0% | −1.7% | −2.3% | −2.7% | −3.6% | −4.3% | −5.5% |
| **1987** | - | −0.1% | −1.2% | −2.3% | −3.3% | −4.0% | −5.5% | −6.6% | −8.2% |
| **1988** | - | −0.4% | −2.1% | −3.7% | −4.8% | −5.9% | −8.4% | −10.0% | −12.2% |
| **1989** | - | −0.2% | −1.1% | −2.0% | −2.6% | −3.2% | −4.1% | −5.2% | −6.7% |
| **1990** | - | −0.3% | −1.1% | −2.2% | −2.9% | −3.6% | −5.0% | −5.8% | −7.1% |
| **1991** | - | −2.4% | −4.1% | −6.0% | −7.5% | −8.5% | −9.8% | −10.9% | −12.1% |
| **1992** | - | −0.5% | −2.2% | −4.3% | −5.9% | −6.9% | −8.5% | −9.7% | −12.0% |
| **1993** | - | −3.5% | −8.7% | −10.5% | −11.7% | −12.6% | −14.0% | −14.9% | −15.9% |
| **1994** | - | −1.0% | −3.3% | −5.6% | −7.9% | −9.8% | −11.4% | −13.8% | −16.6% |
| **1995** | - | −0.6% | −2.3% | −4.2% | −5.7% | −7.0% | −8.8% | −10.3% | −12.4% |
| **1996** | - | −0.6% | −2.9% | −5.4% | −7.2% | −9.0% | −11.0% | −12.5% | −15.6% |
| **1997** | - | −0.5% | −2.6% | −5.0% | −6.7% | −7.8% | −9.5% | −11.2% | −14.0% |
| **1998** | - | −2.0% | −8.6% | −14.5% | −18.0% | −20.6% | −24.0% | −26.4% | −30.3% |
| **1999** | - | −0.8% | −4.0% | −8.9% | −13.0% | −15.8% | −19.2% | −20.9% | −23.5% |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **2000** | - | −0.8% | −2.9% | −5.4% | −7.2% | −8.5% | −10.9% | −13.0% | −16.2% |
| **2001** | - | −0.6% | −1.6% | −2.5% | −3.2% | −3.7% | −4.5% | −5.1% | −5.8% |
| **2002** | - | −0.5% | −2.6% | −5.0% | −6.3% | −7.8% | −9.8% | −11.4% | −13.2% |
| **2003** | - | −1.0% | −4.4% | −8.4% | −10.9% | −12.2% | −14.7% | −16.2% | −18.6% |
| **2004** | - | −0.2% | −1.1% | −2.2% | −3.0% | −3.6% | −4.8% | −5.8% | −7.6% |
| **2005** | - | −2.5% | −8.1% | −14.6% | −18.9% | −22.6% | −26.0% | −27.9% | −29.8% |
| **2006** | - | −0.6% | −2.7% | −4.8% | −6.8% | −7.9% | −10.3% | −12.3% | −15.1% |
| **2007** | - | −0.5% | −1.9% | −3.7% | −4.9% | −5.7% | −7.3% | −8.7% | −10.8% |
| **2008** | - | −0.5% | −1.9% | −3.3% | −4.4% | −5.3% | −6.6% | −7.9% | −9.5% |
| **2009** | - | −0.8% | −2.4% | −4.4% | −5.8% | −6.7% | −8.6% | −9.9% | −12.1% |
| **2010** | - | −0.8% | −5.2% | −9.1% | −10.6% | −11.5% | −13.2% | −14.9% | −17.5% |