Using Water Budgets to Assess Impacts on Streamflow

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Project Structure

• Funding & Project Management
  – EOEA
  – US-AF

• Data Collection & Processing
  – 3 RPAs
  – Chas. H. Sells
  – MassGIS

• Analysis & Reports
  – CRWA
  – ESS Group

• Data Collaborators
  – Communities
  – MassDEP
  – EPA
  – USGS
Project Development

• Methodology Development
• Data Acquisition

• Stony Brook Pilot Project
• Plymouth Carver Aquifer
• Charles River Watershed
  – under review
Why Water Budgets?

- Assess human impacts on streamflow
- Need a balanced, standardized approach
- Results should help prioritize remediation
- Educate & promote sustainable water use
Water Budget Methodology

• Subbasin scale
  – HUC-14 subbasins (2,200 @ 4 mi²)

• Monthly time step
  – focus on wet (Apr) and dry (Sep) months

• Hydrology
  – base flow only
  – urban impacts only
  – all water utilities

• Impact
  – absolute (gallons, cfs, cfsm)
  – relative (% of natural flow)

• Calculations
  – ArcGIS Visual Basic tool
Water Budget Inputs and Outputs

Subbasin Water Budget

- Streamflow In
- Streamflow Out
- Water Supply Input
- Evaporative Loss From Irrigation
- Wastewater Discharge
- Recharge Loss From Impervious Cover
- Wastewater Loss, Including I/I
- Water Supply Input
Water Budget Components
(units are mgd)


Impact = total subbasin gain or loss
SD = wastewater discharge to surface water
SW = withdrawal from surface water
WS = water supply gain
WW = wastewater loss including infiltration from groundwater
IRR = evaporation loss from irrigation
RIA = recharge loss from impervious area
GD = wastewater discharge to ground water
GW = withdrawal from ground water
SFAC = storage factor (0.9 – 1.1)
Water Budget Examples

- **PWS, septic, no IA**
  - water in - no water out = net gain

- **PWS, sewer, no IA**
  - water in - more water out (incl. I/I) = net loss

- **Water withdrawal, no PWS, no WW, no IA**
  - no water in - water out = net loss

- **Wastewater discharge, no PWS, no WW, no IA**
  - water in – no water out = net gain

- **No PWS, no WW, large IA**
  - no water in - water out = net loss
Withdrawals and Discharges

- Monthly flows for 2000-2004
  - filled-in if necessary
- Average monthly flow computed
- River withdrawals & discharges directly from sub-basin
- Well withdrawals converted to stream depletion using StrmDepl (USGS)
- Well withdrawals distributed over subbasins with zone of contribution
Cranberry Bog Impacts

• Reported system areas for 2000-2004
  – filled-in if necessary
• System area distributed over number of number of withdrawal points
• Monthly sub-model developed for 1-ac of cranberry
  – monthly inputs/outputs in ac-ft of water
• Converted to monthly point volumes (mgd) using annual area and monthly factors
Piped Water and Irrigation

- Subbasin transfers computed using system unit flows with people and areas
- People and areas from distribution system maps and new MassGIS population density map
- Monthly irrigation loss computed as:
  - 75% of (monthly use - winter use)
  - Applied to both public/private irrigation areas

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<td>Public water</td>
<td>+WS - WW - IRR</td>
<td>+WS - IRR</td>
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<tr>
<td>Private well</td>
<td>- WW - IRR</td>
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WS = public water supply
WW = wastewater including I/I
IRR = irrigation
Piped Water Distribution System Areas
Effective Impervious Area (EIA)

- Loss assumed proportional to EIA
  - 10% EIA $\rightarrow$ 10% reduction in streamflow
- Subbasin TIA from new MassGIS IA grid
- Subbasin EIA computed from TIA as:
  
  $\text{Effectiveness (\%) } = -22.6 + 1.774 \times \text{TIA (\%)} > 0$
  
  $\text{EIA (\%) } = \text{Effectiveness (\%)} \times \text{TIA (\%)} / 100$
Effective Impervious Area (EIA)
Natural Streamflow Estimation

$$QN_m = \left( \text{Int} + \text{Area}^{AC} \times \text{S&G}^{SGC} \times \text{Prec}^{PC} \times \text{Elev}^{EC} \times \text{Slope}^{SC} \right) / \text{Area}$$

- $m$ = month (1=Jan, 2=Feb, etc.)
- $QN_m$ = natural flow in month $m$ (cfs/m)
- Int = Intercept coefficient (-)
- Area = subbasin area (mi²), AC = Area coefficient
- S&G = percent sand and gravel (%), SGC = S&G coefficient
- Elev = avg. subbasin elevation (ft) from 30-m DEMs, EC = Elev coefficient
- Slope = average subbasin slope (%), SG = Slope coefficient

- 23 USGS index flow gages (Armstrong et al., 2003)
Avg Natural Streamflow (PCAA)
Water Budget Calculations

Impact (mgd) = SD – SW + (WS–WW–IRR–RIA+GD–GW)*SFAC

Impact (cfs/mi²) = Impact (mgd) * 1.547 cfs/mgd / Area (mi²)

Impact (%) = Impact (cfs/mi²) / QN (cfs/mi²) * 100
Database Development

- First water resources database for MA
- Includes spatial (GIS) and tabular data
- Compiles information on withdrawals and discharges from multiple governing agencies
- Help foster interagency collaboration and provided motivation for electronic record-keeping
Water Budget Data Model 1.1

- **ReportedVolumes**
  - **PK**: ReportedVolID
  - Year, MonthNumber, Flow, FlowUnits, FlowStatistic, FlowStatus, ImportFlow, ImportUnits, ImportStatistic, ExportFlow, FromSystem, ExportUnits, ExportStatistic

- **PermitPoints**
  - FK1: WB_PointID, FK2: WB_PermitID

- **Permits**
  - PK: WB_PermitID
  - FK1: WB_SystemID
  - PermitStartYear, PermitEndYear, PermitStatus, TotalPoints, GW_Points, SW_Points, ProgramPermitID, MajorBasinCode, SpecConditions, PermitStartMonth, PermitEndMonth

- **Facility**
  - PK: FacilityID
  - Name, FacType, PublicPrivate, SIC_code, FacDesc, FMF_ID, FacAddress, Fac7n, FacPhone, MuniID, FacAddress2

- **ReportedSystemVolumeAlloc**
  - FK1: FacilityID, FK2: WB_PermitID

- **Systems**
  - PK: WB_SystemID
  - FK1: WB_PermitID
  - PopServedWinter, PopServedSummer, HasServiceArea, NoResConn, NoCommConn, OperatorFacID, SiteFacID, PctResidential, PctCommercial, SystemName

- **Points**
  - PK: WB_PointID

- **SubBasins**
  - PK: SubBasinID
  - HUC10_Code, SubBasinName

- **WaterServiceArea**
  - FK2: OperatorSysID, FK3: ConnectedSysID

- **SewerServiceArea**
  - FK2: OperatorSysID, FK3: ConnectedSysID

- **ULBT**
  - PK: ULBT_ID

- **Municipalities**
  - PK: MuniID
  - MuniName, MuniPop, MuniPopYear

- **ContactInfo**
  - FK1: FacilityID, FK2: WB_PermitID
  - PersonName, ContactID, WB_PermitID, PersonPhone

- **ReportedVolumes**
  - FK1: WB_PermitID
  - PermittedUnits, PermittedFlow, Statistic, MonthText, PermitStatus, Period
Data Acquisition
Automation of the Analysis & Reports

- Calculations, summary tables and impact maps will be generated using VBA / ArcObjects scripts
- Reports templates will import results from database to generate reports using 4Tops
- Database standardization and completeness crucial to success of project
- Automation allows the future development of an interactive scenario tool
STEP 1. GIS Geodatabase

Contains MA Statewide Water Budget Data

STEP 2. MS Word Report Template

STEP 3. MS Access Results Form

STEP 4. 4TOPS Software Generates Individual Reports

2.0 DESCRIPTION OF THE COMMUNITY

The community of Town_Name, Massachusetts encompasses a geographic area of approximately Town_Area square miles and includes the Watersheds.

The watersheds are further divided into sub-basins as defined and used by the USGS Water Resources Division and the Mass Water Resources Commission and as modified by Executive Office of Environmental Affairs (EOEA) agencies. The watersheds in Town_Name are comprised on Sub_Name sub-basins. The geographic location of the watersheds and sub-basins located within Town_Name along with the associated land area are shown on Figure 1.

Land use within the Chelsea is primarily urban. Land use is comprised Agricultural (Per_Ag), Open Space (Per_Open), Water/Wetland (Per_Wal_Wet), Forest (Per_Forest), Residential (Per_Res), and Commercial/Industrial/Transportation (Per_Cit). The current population within

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Stony Brook Pilot
Project completed with funding from USAF

- Watershed Report
  - Maps
  - Tables
  - General Recommendations
- Chelmsford Community Report
  - Maps
  - Tables
  - Specific Recommendations
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Community Remediation Options

- Water Conservation
- Withdrawal Optimization
- Stormwater Recharge
- Wastewater Recharge and Reuse
- Water Transfers and Trading
Charles River Watershed Report
Impact Maps w/o Withdrawals/Discharges

April

September
Water Budgets Implications

- Identifies impacts by subbasin
- Roadmap for protection and/or remediation
- Could set up framework for flow trading
- Can advise regarding withdrawal or discharge placement