

The Hydrologic Signature of Acadia National Park

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INTRODUCTION

Hydrologic Signature: Surface runoff conveyed from the outlet of a watershed can be described by the timing and rate of volumetric water discharge over the period of a year. The hydrologic signature of a stream and defined by patterns of flux over time influences the ecosystem services, availability of aquatic habitat and water quality loads to receiving water bodies such as tidal estuaries. Ecologists place considerable focus on the “natural flow regime” for streams and rivers using the hydrologic signature indigenous to a region (Fig. 1). Central questions arise related to flow regime variability and how a signature pattern of discharge can be modified by human induced climate and land use changes.

Stream hydrologic signatures vary relative to the primary components of a watershed's hydrologic budget. These can be categorically organized by precipitation, runoff and routing processes that are driven by climatic conditions, physiography and location. An important consideration for development of adaptive management strategies for aquatic resources is identification of signature flow patterns and explanations of why they exist relative to the three categories. At the scale of the continent, organizations like the National Park Service can use hydrologic signature information to prescribe strategies to protect and restore aquatic habitats, respond to climate and forecast budgets required for environmental management activities, particularly those related to streams, lakes and estuaries.

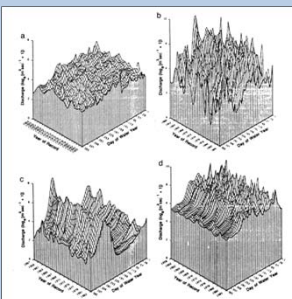
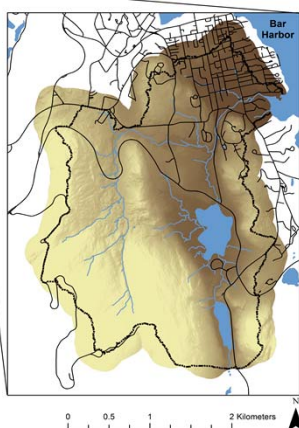


Figure 1: Plot from Poff et al. 1997 showing flow histories of a) Augusta Creek, ME; b) Satilla River, GA; c) Upper Colorado River, CO; d) South Fork Melanese River, OH.

Study Area: Cromwell Brook is located in Mid-Coast Maine on Mount Desert Island (Fig. 2). The watershed terminates in Cromwell Harbor at the southeastern edge of Bar Harbor. The watershed is ~18 km², has moderate to high relief (elevation range ~465 m), is dominated by granite bedrock with limited overburden with soils that are thin or absent. Only 19% of the watershed is developed, mostly outside of Acadia National Park.



Figure 2: Location map of the Cromwell Brook watershed on Mount Desert Island in Mid-Coast Maine. The location of a comparative reference watershed, North Fork Eagle Creek, is shown in the map on the left.



METHODS

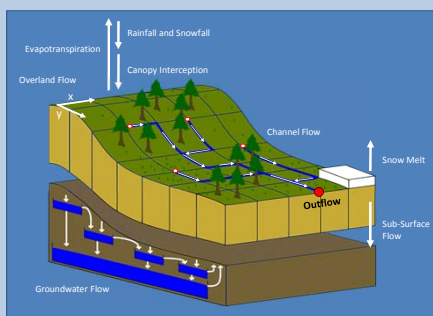
Data Acquisition: Flow monitoring and sampling instrumentation was installed at the bottom end of Cromwell and Kebo Brooks in 2015. Depth measurements are recorded at 10 minute intervals. Rating curves to estimate flow rates from depth recordings were assembled using discharge measurements.



Figure 3: Flow monitoring instrumentation was installed at the bottom end of Cromwell Brook containing water depth sensors, velocity sensors and a pump sampler for the measurement of total suspended solids concentrations.

Terrain data were assembled with attention to acquiring relatively highest resolution in stream channels and around artificial structures such as culverts and dams. Digital elevation (LiDAR) data available from Web sites were supplemented by our own channel mapping and topographic surveys.

Model Domain and Parametrization: Cromwell Brook was modelled using a distributed (gridded), physically based, coupled groundwater-surface water modelling platform. All major processes of the water cycle are represented in the model (Fig. 3).



Watershed parameters were defined through field methods and literature review. The data sources and descriptions are summarized in Table 1.

Figure 4: A diagram representing the model structure and water cycle processes that are accounted for in the model.

Table 1: Data sources for model parametrization.

Data	Source
Climate Data	Multi-sensor (radar and rain gauge) estimates from NWS River Forecast Centers.
Topography	LiDAR from the Maine Office of GIS (MEGIS)
Manning's M (Roughness)	Assigned for land covers based on methods similar to those of Wijesekera et al. (2012).
Leaf Area Index (LAI)	Assigned for land covers based on 2007-2010 monthly averages from NASA's Moderate Resolution Imaging Spectroradiometer.
Rooting Depth (RD)	Assigned for land covers using values obtained from literature (Schenk and Jackson 2002; Schenk and Jackson 2002).
Soil	Defined by SUURGO soil texture categories. All hydrologic properties were averaged for each texture.
Groundwater Table	Estimated based on field observations and previous research in the region.
River Network	Defined by the National Hydrography Dataset (NHD). Cross section geometries estimated from hydraulic geometry relations (Dudley 2004) and field observations.

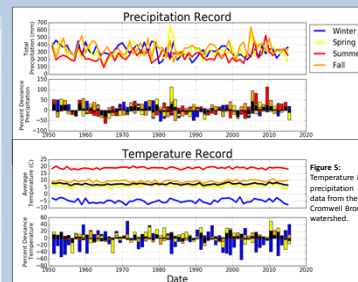


Figure 5: Temperature & precipitation data from the Cromwell Brook watershed.

RESULTS

Observations: Flow observations show distinct flow characteristics between Otter Creek and Cromwell Brook due to storage in the Great Meadow (Fig. 6).

Debris removal from the Great Meadow culvert shows the hydrologic impact of this feature (Fig. 7).

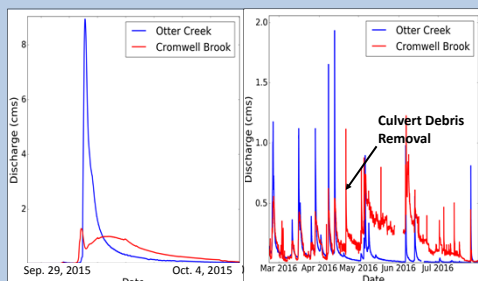


Figure 6: Storm hydrograph comparison between Otter Creek and Cromwell Brook.

Figure 7: Discharge in Otter Creek and Cromwell Brook through the summer of 2016. A sharp separation in the hydrographs is present following the removal of debris from a culvert below the Great Meadow.

Model Calibration: The Cromwell Brook watershed model was evaluated against observed discharge measurements for the time period between July 2016 when new instrumentation was deployed and April 2016 when the Great Meadow culvert was cleared of debris.

Model statistics comparing observed and simulated flow are considered “Good” and “Satisfactory” based on literature classifications of the calibration metrics (Moriassi et al. 2006).

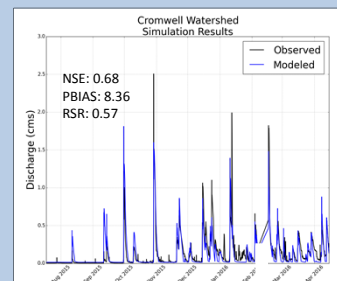


Figure 8: Modeled and observed discharge at the Cromwell Brook.

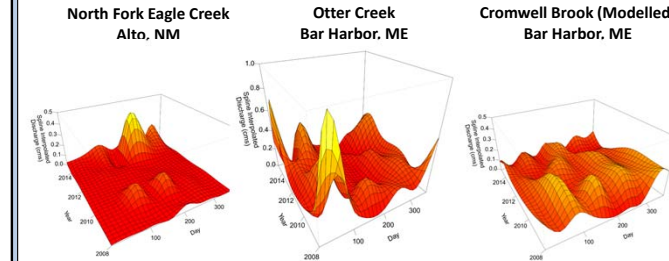


Figure 9: Three dimensional hydrologic fingerprints for Otter Creek and Cromwell Brook compared to a comparably sized western watershed, North Fork Eagle Creek in New Mexico.

Regional Hydrologic Signatures: Eagle Creek has substantially less flow despite its drainage area being nearly double Otter Creek and Cromwell Brook. Conditions are “flashier” with higher, pronounced flow peaks) compared to streams in Acadia National Park (Fig. 9).

Feature Hydrologic Signatures: Otter Creek and Cromwell Brook are similar in their baseflow characteristics and runoff frequency. However, Cromwell Brook has a more “muted” storm flow response due to storage in the Great Meadow, which conforms to trends in the 2D hydrograph plots (Fig. 6).

Cromwell Brook Scenarios: Climate reanalysis data indicated an anomalously high precipitation year in 2005 (~130 cm while the 2000 to 2015 average was ~120 cm). The year was estimated to be representative future climate conditions based on conversations with Maine's State climatologist. The same data sources provides and example of a relatively “average” precipitation year during 2012 based on the long term data record.

DISCUSSION

Observations: Results from our analyses demonstrate the variability in stream hydrologic signatures relative to drivers affecting inputs and losses of precipitation, runoff production and surface flow routing. The measurements and simulation results we have assembled highlight the influence of climate, physiography and man-made infrastructure on hydrologic conditions.

ACKNOWLEDGEMENTS

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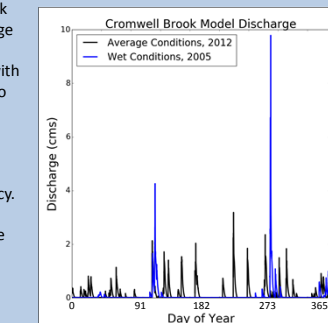


Figure 10: Overlapping modeled flows during 2012 (average conditions) and 2005 (wet conditions) plotted as day of the year on the x-axis.

Trends: Results illustrate the relatively subdued and more annually consistent runoff responses in Acadia NP compared to similar sized watersheds in the southwest. However, results from the two streams in Acadia NP do show the elevated flow conditions that occur due to spring snowmelt. Comparison of the two streams in Acadia NP reveal that manmade structures can alter annual stream flow trends. However, the effects from individual watershed features to not have as much influence on the hydrologic signature as regional climate conditions. Our simulations also show that forecast changes to climate will produce measurable changes in runoff rates. It is not clear how those changes will alter the fundamental fingerprint of streams in the region; however, it appears likely that they may scale similar to the effects of watershed features.

Implications: Adaptive management of streams systems in national parks will require knowledge of annual hydrologic conditions and how they will be modified by climate and land use changes. The results we present here demonstrate a framework through which the changes can be evaluated and compared over a range of scales and scenarios.