**Sara Paper Meeting**

1. Decided SWMM WQ was sufficient for the study? Did you consider any other methods?
   1. Mainly picked SWMM b/c of PySWMM, didn’t look at anything besides PySWMM
   2. Nancy wanted to look at particulate and soluble pollutant, but would have assumed little transformation in system and would flow just like water
   3. Simplifying sediment is assumed to move in the sewer and built in settling and resuspension which is a simplication on particle size – used literature data
      1. Pulled from literature because not in her wheelhouse and wanted her contribution to be on control not on solids movement
      2. Maybe might make more sense to add more detail to that if going to focus on erosion processes – significant literature out there on solids on
2. For your TSS/erosion, any sources you recommend checking out?
   1. Mainly used what was cited, used SWMM manual
   2. Most of the papers used SWMM as their simulator
   3. Fundamental/intro to treatment plant design go into the basics of the physical processes – Metcalf & Eddy, Inc.
3. Words of Wisdom
   1. What do I want my contribution to be? And in order to do that, I need to a computation, experiment, etc. to solve that?
   2. But there is some iteration between what am I showing with this figure and what I want to accomplish
   3. Look at the research questions of my entire dissertation
      1. Nancy had her make a list of research question that could be broad and have narrow questions
   4. Find someone that is more of an expert in WQ that can help guide me
      1. Suggestion: Nancy has had students that have look at stormwater stuff – heavy metals in GSI Andrea McFarland
      2. Hathaway?
4. Equations
   1. Had buildup/washoff equations in the input files of SWMM
   2. For each control asset, put in a treatment function put in the assumed settling/resuspension in SWMM
   3. Abhi added a call for PySWMM to get pollutant information in SWMM

**SWMM Water Quality Modeling**

* **Urban Runoff Quality**
  + Pollutant Object
    - Any pollutant can be included as long as they can be expressed as concentration of mass/volume of water and their masses are additive
    - User supplied properties:
      * Units
      * Rain concentration
      * Groundwater concentration
      * Inflow/infiltration concentration
      * Dry weather flow concentration (typically sanitary sewage flow or indusrial flows)
      * Decay coefficient (first order reaction coefficient)
      * Snow only flag
      * Co-pollutant (name of another pollutant whose concentration adds to the concentration of the current pollutant – ex: phosphorus onto “solids”)
      * Co-fraction
  + Land Use Object
    - ﻿Because buildup data clearly show that different rates apply to different land uses, SWMM allows one to define different buildup and washoff functions for each combination of pollutant and land use.
    - Land use activities examples: residential, commercial, industrial, undeveloped
    - Land surface characteristics: rooftops, lawns, paved roads, undisturbed soils, etc.
    - Used solely to account for spatial variation in pollutant buildup and washoff rates within subcatchments
* **Surface Buildup**
  + Only required if SWMM’s exponential option is used to describe wash off since that function depends on the amount of buildup present. But if using rating curve or EMC, could still be useful to establish a max mass off pollutant that can be removed
  + ﻿Because buildup data clearly show that different rates apply to different land uses, SWMM allows one to define a different buildup function for each combination of pollutant and land use.
  + The buildup of each pollutant that accumulates over a category of land use is described by either a mass per unit of subcatchment area or per unit of curb length.
  + ﻿Because there is no obviously proper functional form that describes pollutant buildup over time, SWMM provides the user with three different functional options for any combination of constituent and land use. These are: 1. power function (of which linear buildup is a special case), 2. exponential, or 3. saturation.
    - A close up of a map

      Description automatically generated
  + SWMM allows pollutant buildup within a given land use area to be reduced by street sweeping operations.
* **Surface Washoff**
  + ﻿Washoff is the process of erosion or dissolving of constituents from a subcatchment surface during a period of runoff.
  + 3 governing equations one can select from in SWMM because sediment transport based theory is often insufficient in practice because of lack of data for parameter evaluation, sensitivity to time step, and discretization and because simpler methods usually work as well .
    - Exponential washoff, rating curve washoff, and event mean concentration washoff
      * Sara used exponential equation!
    - A close up of a map

      Description automatically generated
  + Subcatchment runoff may also contain pollutant loads contributed by direct rainfall and by runon from upstream subcatchments
    - Pollutant streams are completely mixed with the current contents of the ponded water and a mass balance is performed to find the pollutant mass from these sources leaving the ponded surface water over the time step
    - A close up of a map

      Description automatically generated
  + Both Washoff and ponded pollutant loads may be reduced by applying a BMP removal factor to them. A different BMP removal factor can be associated with each pollutant and category of land use.
    - Applied separately to the Washoff rate computed for each pollutant
    - A screenshot of a cell phone

      Description automatically generated
    - For the pollutant load from rainfall/runon across the entire subcatchment (and therefore all land uses) an area weighted average removal factor is used.
* **Transport**
  + 1D transport of dissolved constituents along the length of a conduit (pipe or natural channel) described by a conservation of mass equation – complicated to solve because have an equation for each pipe/channel resulting in a large system of algebraic differential equations that must be solved simultaneously.
  + SWMM uses less rigorous approach where conduits represented as completely mixed reactors connected together at junctions or at completely mixed storage nodes.
* **Treatment**
  + Ideally one would like to model these processes at a fundamental level, to be able to estimate pollutant removal based on physical design parameters, hydraulic variables, and intrinsic chemical properties and reaction rates. With a few exceptions, the state of our knowledge does not permit this, at least within the scope of a general purpose stormwater management model. Instead one has to rely on empirical relationships developed from site-specific monitoring data.
  + The degree of treatment for a constituent is prescribed by the user, either as a concentration remaining after treatment or as the fractional removal achieved. It can be a function of the current concentration or fractional removal of any set of constituents as well as the current flow rate. For storage nodes, it can also depend on water depth, surface area, routing time step, and hydraulic residence time. Because treatment is applied at every time step, the resulting pollutant concentrations can vary throughout a storm event and will not necessarily represent an event mean concentration (EMC).
  + ﻿The hydraulic variables that can appear in a treatment expression include the following:
    - FLOW - flow rate into the node in user defined flow units
    - DEPTH - average water depth in the node over the time step (ft or m)
    - AREA - average surface area of the node over the time step (ft2 or m2)
    - DT - current routing time step (seconds)
    - HRT - hydraulic residence time of water in a storage node (hours).

**Nitrogen in Bioretention Cells Notes**

* **(Liu et al. 2015) Event Mean Concentrations:**
  + Total nitrogen (mg/L)
    - Consists of a few separately identifiable compounds (nitrate, ammonia), and lumped classes of compounds (particulate N, organic N)
    - TKN + oxidized nitrogen
    - Commercial: 1.41
    - Agricultural: 4.14
    - Residential: 1.96
    - Industrial: 1.26
  + Total Kjeldahl Nitrogen (TKN) (mg/L as N)
    - Organic + ammonia nitrogen
    - Commercial: 1.2
    - Agricultural: 1.23
    - Residential: 2.1
    - Industrial: 0.99
  + Nitrate (NO3-) + Nitrite (NO2-) (mg/L)
    - Also referred so as oxidized nitrogen
    - Commercial: 0.24
    - Agricultural: 1.48
    - Residential: 0.67
    - Industrial: 0.3
* [**EPA: Urban runoff (mg/L):**](https://www.epa.gov/sites/production/files/2015-10/documents/usw_b.pdf)
  + Total N: Range 0.4-20.0 (2)
* [**EPA 2008 Urban runoff- Nitrogen, Total Kjeldahl (mg/L):**](https://www.epa.gov/sites/production/files/2015-10/documents/nrc_stormwaterreport1.pdf)
  + All Areas Combined Median: 1.2
  + All Residential Areas Combined Median: 1.2
  + All Commercial Areas Combined Median: 0.9
  + All Industrial Areas Combined Median: 1.1
  + All Freeway Areas Combined Median: 1.2
  + All Institutional Areas Combined Median: 0.6
  + All Open-Space Areas Combined Median: 1.2
* [**BMP Database – Influent to BRCs (mg/L):**](http://www.bmpdatabase.org/Docs/2014%20Water%20Quality%20Analysis%20Addendum/BMP%20Database%20Categorical_StatisticalSummaryReport_December2014.pdf)
  + Total Nitrogen: 1.16
  + Total Kjeldahl Nitrogen: 1.10
  + Nitrate (NO3): 0.31
  + Nitrite & Nitrate (NO2+NO3): 0.35
  + Nitrogen Oxides (NOx): 0.35

**(Lucas & Greenway, 2011):**

* **Immobilization**
  + Microbial immobilization more rapidly than plant uptake so it’s the initial process by which nitrogen is retained in soil.
  + Distinct preference for NH4+ (valency requiring the least energy for protein synthesis). Immobilized 5X faster than NO3-.
  + Upon cell death, nitrogen mineralized back into by NH4+ by extracellular enzymes secreted by other microbes, or incorporated to soil organic nitrogen (SON) as long-term immobilization.
  + In soils high in organic matter, immobilization rates approach 1.0 g/m2d.
  + Because organic matter content accelerates microbial respiration, immobilization rates increase in the presence of plant residues.
  + Suggests several hours of retention time could be adequate for immobilization of inorganic nitrogen found in runoff.
* **Mineralization & Nitrification**
  + **Nitrification: process of nitrogen compound oxidation (loss of electrons from nitrogen atom to the oxygen atom)- catalyzed step-wise by a series of enzymes.**
  + After microbial immobilization of inorganic nitrogen and organic nitrogen, mineralization, ammonification, and nitrification by microbes turns over NH4+ and NO3- into the rhizosphere for subsequent plant uptake.
  + Initial immobilization/synthesis is recycled rapidly to ensuing mineralization and nitrification.
  + In nitrogen-enriched settings, nitrification represents the dominant pathway for NH4+ transformation.
* **Denitrification** 
  + **Denitrification: process where nitrate is reduced and ultimately produces molecular nitrogen through a series of intermediate gaseous nitrogen oxide products.**
  + Given adequate organic carbon energy sources when anoxic conditions are present, denitrification will also transform NO3-.
  + First-order reaction approaching completing in 10-12 hours
  + When established, plant rhizodeposition provides adequate amounts of biomass energy for denitrification, even at high nitrogen loading rates.
* **Plant Uptake**
  + Plant uptake the aboveground shoots and p and belowground roots and rhizome is the final step in sequestration process initially mediated by immobilization.
  + Annual uptake varies from 15 -84 h/m2y
  + Uptake is more effective in certain plants than others and is correlated with better nitrogen retention
  + Greatest aboveground biomass nitrogen uptake occurs in an annual cycle, beginning in spring, peaking past midsummer, and ceasing by autumn. Accumulated nitrogen then is released during senescence in the fall and over the winter.
  + If uptake is conserved a viable process for nitrogen retention, it is necessary to harvest aboveground biomass, at least annually. Increased frequency of harvesting increases nitrogen uptake.
* **Nitrogen Processes in BRC**
  + Nitrogen cycling time is many multiples of HRT
  + Nitrogen can be intercepted and transformed within a period as short as 3-5 hours in planted systems
  + Expected that better nitrogen retention would be correlated with slow infiltration/application rates and or low hydraulic loading rates relative to media pore volume
    - Low infiltration rates permit more residence time during events
    - Low hydraulic loading permits more runoff to be retained within the system until discharged at the next event
    - Cumulative total nitrogen retention was highest in the loam treatment with infiltration rates of 1cm/h, while in sand treatment restricted to 5 cm/h was half as effective. However, the loam treatment could not treat nearly as much of a volume, resulting in more flows being bypassed as the system overflowed.
    - Unregulated flow regime will not provide enough retention time for effective nitrogen retention processes during events, so more runoff nitrogen would pass through relatively unaltered.
    - On the other hand, increasing retention time to several hours will permit more nitrogen to be immobilized initially for subsequent transformation processes to occur. Retained within the profile, nitrogen remains available for eventual plant uptake, sequestration into SON, and/or denitrification.
    - Increasing retention time for a fraction of an hour to several hours, nitrogen retention resulted in a 2.7 times as much NOx being retained compared to free discharge system, and at least 2.2 times higher total nitrogen retention.

**(Waller et al. 2018)**

* Stormwater contains nitrogen in many forms, including particulate organic nitrogen (PON), dissolved organic nitrogen (DON), and dissolved inorganic forms such, as ammonium (NH4+), nitrite (NO2−), and nitrate (NO3−).
* Denitrification is a microbial form of anaerobic respiration that is valuable for N management because, when carried out to completion removes mobile NOx forms from soil or water by transforming them into inert nitrogen gas (N2).
  + Need: (1) presence of denitrifying organisms; (2) an organic carbon source as an electron donor; (3) oxygen deficient environment coupled deficient environment coupled with oxidizing N species to serve as alternative electron acceptors.

**Model Notes**

1. Talking with Abhi, we can use what we have in SWMM to do the hydraulic modeling. Shouldn’t be an issue. If we sit together, can built it out in a week or so. Biggest step is the water quality modeling.
2. Going through the Bioprocess textbook and refreshing myself on reactor models
   1. Literature standards
      1. bioretention cells/swales: CSTR or PFR
         1. P paper was PFR
         2. Other paper CSTRs in series
      2. constructed wetlands: CSTR in series or PFR
         1. Or CSTRs in series
         2. Literature leans towards PFR
      3. ponds:
         1. Most ponds behave in an intermediate fashion between plug flow and complete mixing due to short-circuiting, dead zones, and incomplete mixing (Thackston et al. 1987)
         2. Literature leans towards CSTRs
      4. Paper modeled wetlands, ponds, vegetated swale, sediment basins, and biofilters with a single algorithm. Assumed everything was CSTRs, and put them in series when needed (highly cited paper):
         1. “However, since pollutant removal depends on flow behaviour, the continuously stirred tank reactor (CSTR) concept is used to account for the hydrodynamics within a treatment device. Where the device has a high degree of turbulence or short-circuiting (such as in a sediment basin), the k–C\* model is applied through a small number of CSTRs in series, whereas a well-designed wetland with even flow distribution is modelled by a high number of CSTRs. The unified model has been successfully tested on a series of treatment measures—a wetland, pond, swale, grass filter, gravel filter, and large lake.” (Wong et al 2006)
         2. “As the number of CSTRs in series increases, the residence time distribution becomes more like plug flow (such as may be observed in a long-vegetated swale), and the time-lag of the peak discharge concentration is closer to the nominal detention time (given by volume/discharge).
   2. Use CSTR’s: I think the literature overall leans towards CSTR’s.
3. Thinking about water quality equations:
   1. Liu 2013 dissertation created models for nitrogen and phosphorus
      1. 4 differential equations for each species of N and P
      2. Used Green Ampt because it is a first order ODE
   2. Wong 2006 paper used a simple kC method
      1. Worked for all types of GSI
      2. Is it too simple? Would need to calibrate for each site?
   3. Stentoft 2019 paper uses a modified activated sludge model for control for nitrogen removal
      1. It is for predictive control, but I’m sure we could modify for state feedback control if we want?
      2. General framework for how we should move forward with thinking about water treatment plant?
   4. Original P paper
      1. No biochemical process for P removal
         1. “P in urban runoff is distributed between dissolved forms (generally organic P and phosphate species) and P affiliated with particulate matter. Bioretention removal mechanisms will differ for each. Particulate P is generally well-removed via filtration via filtration mechanisms in bioretention systems, similar to particulate matter (Li and Davis, 2008a, 2008b, 2009; Liu and Davis, 2014). Although vegetative uptake and microbial immobilization are important, the critical dissolved P removal mechanism for bioretention is adsorption onto the media during transport through the media (Lucas and Greenway, 2008, 2011). Therefore, media selection and characteristics will play critical roles in the performance of bio-retention SCMs in P management (Erickson et al., 2007; Lucas and Greenway, 2011; O'Neill and Davis, 2012a, 2012b). P uptake via adsorption will be controlled by the adsorption capacity of the media and the previous exposure history of the media to the adsorbate. With the accumulation and eventual saturation of P in the media, the media should gradually demonstrate P adsorption breakthrough and exhaustion.”
   5. Figure out biochemical processes for nitrogen

**Bioprocesses Textbook Notes:**

* Anaerobic = total absence of free oxygen (O2) or bound oxygen (NO2, NO3)
* Anoxic = absence of free oxygen, but presence of bound oxygen.
* An aerobic zone is required:
  + Require for nitrogen removal because nitrifying bacteria are obligate aerobes
  + Either aerobic or anocix zone followed by an anaerobic zone is required for phosphorus removal because the stored and exogenous organic material must be oxidized by the phosphate accumulating organisms (PAOs) in an aerobic/anoxic environment to generate the energy required for growth

**3/4/19 Notes from Branko Meeting:**

1. **Inventory how we do this in SWMM:**
   1. LID editor: why it’s good, why bad
   2. My P paper method: why it’s good, why bad
   3. See where SWMM does good for the different processes
   4. How do include tile drains? Maybe be able to add that?
   5. Complexity we choose should match end goal and the data we have
   6. Water quality model
      1. What are we doing in wastewater modeling- we want to do the same things but in the watershed.
         1. SUMO – possibly in Python can maybe bring that into SWMM
         2. Settling, digester, etc.
         3. Generic treatment train
      2. General model

**Water Quantity Model:**

* Thus, a suitable model for this is required to model: multiple subsurface media layers, including different materials for each layer (such as soil or any other porous materials); ponding on the surface; drainage of the lowest layer; water movement in the unsaturated and saturated zones; a complete water balance model to consider interception, water uptake by roots, evaporation, transpiration and snowmelt.
* Need dynamic wave method for hydraulic modelling
  + If the objective is to design the real-time control of SCNs and backwater phenomena plays an important role, a dynamic wave modelling approach is required
    - Hydrodynamic models of overland flow and channel flow are based on the shallow water wave theory described by the St Venant (SV) equations. These models are derived from either the kinematic wave (KW) approximation, the diffusion wave approximation (DW), or the dynamic wave (DYW) representation of the SV equations.
* Possible Modeling Options:
  + Only SWMM does dynamic wave modeling!
  + GIFMod and HYDRUS 1D are the best (both open-source)
    - Downsides:
      * Does not allow for sloped surface modeling (like grass swales) but SWAT does
      * Restricted to runoff volume calculation and do not calculate the flow time series (i.e., the hydrograph).
      * Steady state (no flow routing) method only
    - Upsides:
      * Allow for fine to course time steps
      * Use Richard’s equation for the time series of infiltration. In addition, using Richard’s equation allows for modelling multiple layers of soil and modelling the water movement occurring within the soil layers.
      * GIFMod: includes run-on and evaporation
      * HDYRUS 1D: includes evaporation and water uptake by plants
      * HYDRUS also has 2D and 3D options
        + Has been validated with soil moisture sensor data
    - Method of discretization of soil layers is different. HYDRUS 1D uses the conventional mesh generation method and numerical method computations, while GIFMod uses soil blocks and analytical solutions.
    - HYDRUS 1D: Source code can be complied using Fortran complier
  + SWAT for certain aspects (open-source)
    - most thorough water balance model of 11 models in 2018 review paper
      * SWAT considers solar radiation, wind speed and temperature for computing other parameters such as evaporation and snowmelt. Using these parameters for hydrological modelling, SWAT computes soil water content, evapotranspiration, crop growth, pond and reservoir water balance, groundwater flow and height. These computations are also carried out on occasions when the precipitation is not enough for generating runoff or when the precipitation is zero. This approach is helpful in long-term hydrological modelling of LIDs. In long-term modelling, numerous wet- and dry-period cycles occur, and during the dry period, the change in GI characteristics such as soil moisture content is important and is computed by SWAT.
    - Can model multiple layers (up to ten layers of soil or growing media)
  + Could use modified Green-Ampt or Holtan for infiltration (Shao and Baumgartl 2016)
    - Did not vary significantly with soil type, topography, or rainfall conditions
    - Very sensitive to the final steady infiltration capacity
  + Could use “3 bucket” approach (Shen et al 2018; Zhang et al 2016)
    - Could take in soil saturation sensor data and rain fall data
    - Water mass balance equations for each bucket solved for key variables: water depth in ponding zone, saturation of filter media, and water depth in submerged zone.
    - Flow equations are solved explicitly in time using Euler scheme
    - Flow over the weir is the only flow that is solved implicitly (flow at a time step t is dependent upon depth in the pond at the same time step t, so that the mass balance equation in the pond has to be solved iteratively)
    - Calibration term: saturated hydraulic conductivity (or if using newer version, also the plant coefficient for evapotranspiration)
* Include vegetation or no vegetation

**Water Quality Model:**

* **Types of treatment:**
  + **Physical processes**
    - Settling
    - Filtration
    - Volatilisation
  + **Physico-chemical processes**
    - Adsorption
    - Flocculation
    - Precipitation
  + **Biological**
    - Plant and algal uptake
    - Microbial degradation
    - Nitrification and de-nitrification
* **Types of GSI to include:**
  + **Bioretention swale (Savage- Toledo):** A vegetated swale or bioretention swale is an excavated trench ﬁlled with porous media (bioretention component) to create a broad, commonly parabolic or trapezoidal shallow channel (swale component) having vegetation cover on the side slopes and top layer.
    - **Hydrologic mechanisms:** Infiltration, retention
    - **Treatment mechanisms:** The swale component promotes pre-treatment of storm water by removing coarse to medium sediments, whilst the bioretention component removes ﬁner particulates and associated pollutants through ﬁltration, inﬁltration, adsorption and biological uptake.
  + **Detention/retention ponds/basins (AA):** Storm water facilities that provide storage for storm water runoff to be retained or detained. The key difference between retention and detention basins being that, in the case of detention basins, storm water is detained for a period of time and then slowly released into a waterway through a designed outlet. In the case of retention basins, storm water is retained and not released into a waterway. Detention/retention basins allow inﬁltration of storm water during the detention period.
    - **Hydrologic mechanisms:** Detention/retention
    - **Treatment mechanisms:** Physical settling of suspended solids
  + **Bioretention basins (cells) (Toledo Zoo):** Treatment devices that treat storm water runoff by passing through prescribed ﬁlter media with planted vegetation on the surface. Bioretention basins incorporate both vegetation and underlying ﬁlter media for removal of pollutants. Unlike bioretention swales, bioretention basins are not required to convey storm water runoff over the system surfaces, but the runoff is intended to pool on the surface, promoting inﬁltration and percolation through the ﬁlter media.
    - **Hydrologic mechanisms:** Infiltration, detention/retention
    - **Treatment mechanisms:** Inﬂuential factors include vegetation type, hydraulic loading, detention time, hydraulic conductivity of the ﬁlter media and size ratio.
  + **Constructed wetlands (AA):** Artiﬁcial, shallow and extensively vegetated water bodies. Constructed wetlands are primarily created for storm water pollutant removal.
    - **Hydrologic mechanisms:** Inﬁltration, evaporation, retention
    - **Treatment mechanisms:** Settling, vegetation uptake, adsorption, ﬁltration and biological decomposition
  + **A general model for all 4 methods must include:**
    - **Hydrologic mechanisms:** infiltration, evaporation, retention, detention
    - **Treatment mechanisms:** settling, filtration, adsorption, biological treatment
* Could use “3 bucket” approach
  + Transport module simulates transport and removal to occur within a series of connected tanks, where each tank represents on of the biofilter zones.
    - Can have equations for each layer if we want since different processes occur in different layers
  + Uses methods I’m familiar with from 590: calculating advection based on Peclet number and using central differences numerical scheme for advection and diffusion processes
* Could take some elements from SWAT – open access and open source (last update 2016)