DRYLANDS RESILIENCE INITIATIVE [DRI]:
Digital Tools for Sustainable Urban Design in Arid and Semi-arid Urban Centers

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Drylands Resilience Initiative [DRI]:
Data-driven Decision Support for Water-Smart Planning and Design

Led by the Arid Lands Institute (ALI), the Drylands Resilience Initiative [DRI] brings together collaborators from design, science, and policy to envision and realize an abundant future in drylands.

Our goal is to accelerate planning, design, and development that results in local, low-carbon water reserves in dry cities in the US West and around the world.

With the support of the AIA College of Fellows 2015-2017 Latrobe Research Prize, DRI collaborators honed and tested Hazel, a powerful new digital design tool for optimizing the capture and reuse of stormwater.

The Challenge + Opportunity

Freshwater resources are changing globally. Climate change is projected to reduce renewable water resources significantly in most dry subtropical regions, exacerbating competition for water among agriculture, ecosystems, settlements, and industry, and undermining water, energy and food security for as many as 4 billion people living in water-stressed environments worldwide (IPCC, 2014).

Accelerated action in urban centers is essential to global climate change adaptation (IPCC-2, 2014). However, planners, architects and urban designers lack tools for effectively engaging water issues crucial to the design of adaptation in drylands (Bach, 2014).

Building on previous research and a proof-of-concept model, DRI collaborators set out to expand, refine, and test Hazel, a digital tool for water-smart urban design in water-stressed environments.

Hazel is a geospatial decision-making tool that assesses suitability for stormwater capture and groundwater recharge, and provides cost-benefit analysis to designers and stakeholders.

Research Objectives

With Latrobe Prize funding, DRI collaborators focused on two particular questions:

- Metrics: How do we quantifiably evaluate the impacts of new distributed stormwater capture interventions on the existing built environment?
- Interface: How do we make a complex, data-rich tool accessible and effective for planners and designers?

Research Outcomes

During the Latrobe grant period, DRI collaborators:

- Engaged over 1,200 stakeholders from architecture, landscape, engineering, planning, development, policy;
- Identified stakeholder ‘pain points’ in the planning and design process;
- Incorporated an expanded set of metrics and methods for measuring costs and benefits;
- Integrated expanded data sets;
- Enlarged and refined Hazel’s computational capacity;
- Designed an interface for use in professional planning and design settings;
- Performed focused testing with industry partners;
- Engaged students and communities in speculative building, landscape, and urban-scale design scenarios;
- Explored impact on complementary policy and financing options.

In April 2017, DRI collaborators presented a simulation of the revised and expanded Hazel at the national AIA 2017 conference in Orlando. Using a 12-acre demonstration site in the San Fernando Valley, DRI team members demonstrated Hazel's capacity for analyzing complex data at ultra-high resolution, computing suitability for stormwater capture and storage, recommending BMPs, evaluating economic and environmental costs/benefits, and providing rapid feedback for meeting and exceeding regulatory requirements.

Beyond accelerated site design at the scale of the parcel, the team also demonstrated Hazel operating at the scale of the urban watershed. When a green infrastructural approach to a site condition or building typology is replicated across suitable zones identified by Hazel, the tool visualizes and quantifies impacts, allowing planners and resource managers to evaluate and prioritize investment in green infrastructure networks.

By operating across scales, from individual parcel to networked basin, the tool facilitates coordinated decision-making that favors optimized hydrologic function for the urban watershed as a whole.

In complement to the tool, DRI team members also researched and recommended public policy and financing innovations to advance water-smart urban development.

Post-Latrobe

DRI collaborators continue to work on:

- Developing and funding a fully automated tool;
- Seeking early-adapters from the academy, the profession, and the public sphere;
- Testing fundamental assumptions about Hazel's users, applications, and outcomes;
- Bringing the tool to widespread use.

Challenges to Resilient Water Supply in Drylands

A growing population. A changing climate. What's the problem?

Globally, the hydrologic cycle is rapidly changing…
Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions, exacerbating competition for water among agriculture, ecosystems, settlements, industry and energy production, affecting regional water, energy and food security for as many as 4 billion people living in water-stressed environments worldwide. Arid urban centers and regions face unprecedented challenges and uncertainties in timely adaptation to climate change, and science suggests that action within urban centers is essential to successful global climate change adaptation (IPCC, 2014).

…and Requires Changes in the Design of the Built Environment.
To decrease susceptibility to water stress and build water supplies within arid and semi-arid communities, we have identified three region- and discipline-specific challenges to address, across multiple scales. Work funded by the Latrobe Prize addressed each of these elements.

[1] Uncouple the Water-Energy Nexus

It takes a lot of water to generate energy —almost one-half, 45% in 2010, of the United States' total water supply withdrawals goes to the thermoelectric power-generating sector (USGS, 2014). And it takes a lot of energy to bring us our water—20% of California's annual energy budget goes to water's capture, distribution, treatment, and use (Wilkinson, 2006). As Peter Gleick of the Pacific Institute and others have documented extensively, the relationship between water, energy use, and heat-trapping greenhouse gas emissions is intertwined and self-limiting, particularly in the West, where much of our energy is generated by coal- and gas-fired power plants. The more carbon-intensive energy we use to deliver snowmelt across deserts and mountain ranges, the more we contribute to a warmer atmosphere, shrinking snowpack, and depleted water supplies.

Our claim is that no water solution is truly a solution unless it is also a low-carbon solution. Uncoupling water's capture, treatment, distribution, and use from energy-intensive delivery systems is critical to climate mitigation and adaptation in drylands.

Our challenge: How do we support planners, architects, and policy makers to design and build environments that get more value out of water with less energy added?

[2] Anticipate Hydrologic Variability

The primary projected impact of climate change on the US West is increased hydrologic variability in the following forms (IPCC, 2014).

- Decreased snowpack,
- Longer drought periods, and
- Infrequent, intensive rain events.

Sixty million people in the US West, one third of them in the greater Los Angeles region, depend on dwindling snowpack for water, delivered via energy- and carbon-intensive conduits from remote ecosystems (IPCC, 2014-2). At the same time, local stormwater delivered by less frequent but more intensive rain events is still sent to 20th-century channelized flood control structures as waste. Even with heavy precipitation in California—snow up north, rain in the south—in 2016 / 2017, the question facing the US West isn't whether or not the recent drought is over. The question is whether we are actively getting ready for the next one.

Our challenge: How do we support planning and design that embraces infrequent but intensive rainfall as asset not flood risk, reducing vulnerability to drought cycles and dependence on variable snow-melt?

[3] Maximize Local Resources

Localization strategies (harvesting stormwater; recycling wastewater; and conserving industrial, commercial, and domestic water) together have the potential to offset dependence on traditional sources such as overdrawn groundwater and energy-intensive water imports (MWD, 2011). In theory, Los Angeles could meet up to 82% of its current water demands by maximizing use and recovery of rain and stormwater resources while improving water use efficiency and recycling—over a third of that can come from stormwater (MWD, 2011).

Within Southern California alone, up to 500,000 acre feet/year (162 billion gallons) of stormwater is sent unused as discharge into the Pacific Ocean (MWD, 2011. That is enough rainwater to meet the needs of 2.5 million Angelenos at current usage rates (no conservation measures in place).

Increasing local water reserves through stormwater capture will not only reduce vulnerability and mitigate carbon outputs, it will also reduce flood risks, lighten pollutant loads downstream, and alleviate pressure on the upstream ecosystems (eg, Colorado River, San Joaquin Delta, Owens Valley) upon which imports depend.

Our challenge: How do we quantify impacts of design choices so that costs and benefits of stormwater capture are rapidly understood and rigorously assessed?

Challenges Require New Decision-Making Tools

So if capturing stormwater represents a significant opportunity to build local water supplies, buffer against decreasing snowfall and longer drought periods, reduce downstream flood risks and pollutant loads, and pivot to a low-carbon economy, what are our obstacles for incentivizing more of its use?

Overcoming Data Insufficiency

Architects and urban designers lack integrated data and support tools for effectively engaging the design of adaptation in drylands (Bach, 2014). Complex and/or insufficient data about water quality, quantity, and jurisdictional oversight separates most water-related thinking from the design process, relegating it to the domain of regional planning and specialized technical consultants, and removing it from the process and logic of site-specific place-making. General guidelines---such as 20% reductions of water use or infiltration of all stormwater runoff on new construction sites---are attainable. However, they are not always optimal or, in some cases, even wise.

The data is there (in some cases), but its **complex**, **disparate**, and **inaccessible** and using it for providing answers to the following questions remains time consuming and resource intensive.

Where are the most strategic locations for maximum capture at minimum cost?
What are the impacts of my proposed capture methods?
How do we make coordinated, precise, and strategic investments, rather than blanket the city with well-intentioned policies that are expensive, and perhaps counterproductive, to comply with?
Within a fully built-out urban environment, where are the best places to intervene?
Above ground, where does stormwater accumulate and flow?
Below ground, what local conditions favor aquifer (groundwater) recharge?
Where is geology suitable or unsuitable?
Where does contamination limit infiltration advantages?
When favorable circumstances for surface capture and subsurface storage align, what are the best practices to use?
What will they yield?
With what costs?
What benefits?
And when optimal circumstances do not align—due to unsuitable geology or dangerous contamination levels, for instance—what are planners' and designers options?
Again, with what costs and what benefits?

Our challenge: Provide architects, urban designers, and resource managers with access to complex hydrologic site-specific data quickly to aid in making disciplined water choices that align with, and magnify, their values and priorities.

Overcoming Jurisdictional Boundaries

Even where there is wide recognition that stormwater will make up an important part of a city' future water supply—as there is in Los Angeles—major actors including the Department of Sanitation, LA County Flood Control, Los Angeles Department of Water and Power, and the Mayor's sustainability plan often have goals and priorities that are constrained by jurisdictional authority and political boundaries. Data gaps, funding gaps, and scale gaps hamper coordination, velocity, and effective optimization across geography and sectors.

Our challenge: Provide site-specific data in larger basin-wide context to facilitate cross-jurisdictional dialog, collaboration, and bargaining for collective objectives.

Overcoming Financing Obstacles

Researchers, public agencies, and non-governmental organizations across the arid west are coming to terms with the implications of climate change, the water-energy nexus, infrastructural obsolescence, and the need for localization. Prioritizing stormwater capture as one piece of the water portfolio is widely recognized. Nonetheless, questions remain: How do you pay for new systems? How do you incentivize public support? Where are stormwater capture investments best leveraged for multiple benefits, or strategically inserted into other forms of public investment (transit, housing)?

Our challenge: To provide cost-benefit metrics, from social equity to ecosystems services, that allows for rapid prioritization and opportunity for partnerships, on both private and public property, for both existing and new development.


Hazel version 1115_22May
surface
% IMPERVIOUS AREA
71%
LOT Average
STORM WATER RUNOFF
3/4"
465,596 gal
1,762.4 m³
1.43 acre-ft
85th %
580,014 gal
2,195.6 m³
1.78 acre-ft
% IMPERVIOUS SURFACE
< 2 %
10 %
30 %
50 %
70 %
> 90%

Hazel Overview:

Hazel (v2.0) is a digital decision support tool that is designed to optimize the performance of distributed stormwater capture green infrastructures within urban settings. More specifically Hazel can tell a user where stormwater can be safely and effectively infiltrated, treated, stored, and/or re-used, down to a resolution of 2 square feet. Hazel streamlines disparate precipitation, soils, urban land use, and groundwater contamination data and converts it into dynamic, graphically based outputs. Those outputs enhance and accelerate a high-precision, multidisciplinary, and transparent design and planning process that:

- Couples surface and subsurface conditions for assessing the complex relationship between safe infiltration of stormwater within areas of known surface or subsurface contamination / impairment;

- Assesses suitability, location, and right sizing of best management practices by providing computer-assisted techniques for site-specific identification of USEPA and Los Angeles County approved stormwater best management practices;

- Provides high resolution, remote sensing derived, impervious surface and predicted runoff volume analyses using variable design storms, from the regulatory-mandated 85% rainfall intensity to downscaled, future regional climate change induced storm intensities.

Development of the Hazel modeling tool was informed by an objective research path supported through hypotheses addressing central research questions, outlined below.

Task 0:
Latrobe Research Objectives: Identifying New Opportunities for a Resilient Water Supply in Drylands

Partners in the Drylands Resilience Initiative [DRI] recognize that these challenges require a multidimensional response drawing on a variety of disciplines and skills, and that ultimately the urban sustainability agenda will need more than scientific knowledge and research to be successful (NRC, 2010). It requires linking findings and insights across disciplinary boundaries (NRC, 2010) and incorporating design visioning to strengthen and integrate multidisciplinary, evidence-based approaches.

Given the challenges outlined above, new decision-making tools and methods would have to:
• Streamline access to disparate sources of data;
• Operate at hyper-local and regional scales;
• Couple surface and subsurface high-resolution data;
• Compute costs/benefit of design scenarios.

As built on previous research by ALI, Hazel (v1.0) converts high-resolution geospatial modeling of precipitation, soils, urban land use, and groundwater contamination into a dynamic, graphically-based digital tool. Hazel has the capacity to provide architects and urban designers with relevant parameters for precise hydrologic functions—the capture, retention, infiltration, distribution and/or treatment of stormwater runoff—with data that is site-specific within 6.5 - 100 ft^2 set across a 200-square-mile study area.

At the core of the DRI Latrobe Research proposal were two central questions:

Latrobe Research Question 1:
How do we evaluate the impacts of integrating new, multi-scalar, distributed water infrastructures into the existing built environment?

Latrobe Research Question 2:
How do we make a data-rich, accessible decision-making tool available to planners and designers?

As a design-centered team, our assumption going into this process was clear: if the tool is not designed with its end users—planners, developers, architects, urban designers—in mind, we will have moved no closer to the goal of a water-smart built environment, one that is not only hydrologically optimal, but also visually, spatially, and experientially inspiring.

Recognizing that meeting the needs of our potential users underlies all work for the grant period, we deemed it "Task 0:" articulating how Hazel can best support design professionals as leaders in sustainability and climate resilience, and how Hazel can best support planners and resource managers to recognize potential investment in green infrastructure design.

Latrobe Research Objectives
As a result of Task 0, DRI partners defined our research objectives from feedback gathered interviewing practitioners and educators in architecture and allied disciplines to identify the potential value of Hazel to professional practice:

- Making the complexity of urban systems more accessible at the scale of where architects and designers typically work;
- Making educated decisions more rapidly/effectively/efficiently;

- Ruling out inappropriate approaches rapidly early in site planning, feasibility stages;
- Bringing stakeholders together around common objectives through visualization;
- Fostering interactive, scenario-based planning discussions;
- Growing more effective/influential outside of architecture, including shaping policy;
- Visualizing possibility, generating scenarios.

Partners and stakeholders, especially those in policy and resource management, also identified value at the urban and regional scale. Hazel can provide policy makers with support:

- Prioritizing investments;
- Identifying locations where hydrologic opportunities align with social equity objectives;
- Leveraging housing, transit, or infrastructure investment to achieve resilience goals;
- Aligning zoning and building practices to support watershed health;
- Visualizing technologies/systems/infrastructures in specific locations;
- Quantifying construction, maintenance, operation costs early in the evaluation process;
- Assessing multiple economic, environmental, cultural benefits to community;
- Anticipating impacts on water rights and water governance.

A series of work-related tasks were developed for supporting our hypotheses and addressing the identified research objectives. Specifically for research question no. 1, the central work tasks were:

Task 1: Confirming the modeling system architecture;
Task 2: Assessment of data needs with model structure;
Task 3: Model development.
Task 4: Uncertainty Analysis (of data);
Task 5: Information Synthesis;

For research question no. 2: the central work tasks were:
Task 6: Iterative Update and Feedback;
Task 7: Decision making and Policy Impacts
Task 8: Preliminary dissemination with Partners;
Task 9: Preliminary dissemination with Public

Who are the potential users of Hazel?

We designed Hazel to help the needs of two sets of users. Architects and designers, typically within the private sector, as one main user group and planners, urban water managers, utilities, and governmental agencies, typically within the public sector, as the other.

Architects and Designers

Needs: principally concerned with gaining competitive advantages, maximizing client budgets, and meeting regulatory requirements at the *scale of the lot* and includes understanding:
- How much stormwater is flowing onto or near the lot of interest;
- How much stormwater is generated from the lot of interest;
- How much stormwater is leaving the lot of interest;
- What is the performance in water quality and water quantity pre and post BMP deployment on a lot of interest;
- What is the cost of performance for both pre and post BMP deployment;

Public Agencies, Utilities, and NGOs

Needs: principally concerned with meeting water supply and water quality targets *at the scale of the district, basin or sub-basin* and includes understanding:
- Where is stormwater infiltration optimized (lowest cost per volume infiltration);
- Where is stormwater retention and on-site use most appropriate;
- What are the performance metrics to achieve local water security by quantifying:
  Carbon offsets (GHG)
  Embedded energy per unit volume infiltrated stormwater (kWhr/acre-ft)
- What are the potential downstream flooding reduction impacts;

It was critical to design the tool to bridge these two scales, making it possible for both sets of users to work in concert: architects and their clients making appropriate decisions for optimal hydrologic health at the parcel scale; public utilities having the ability to identify, invest in, and network strategically advantageous sites at the scale of watershed and sub-watershed.

By streamlining disparate data, providing hi-resolution analysis, and visualizing results, Hazel allows for prioritization and coordination of green infrastructure investments, across scales and jurisdictions.

Task 1:
Modeling System Architecture
The Hazel system architecture is now comprised of three distinct working elements, with each described in Task 2 and 3 below.

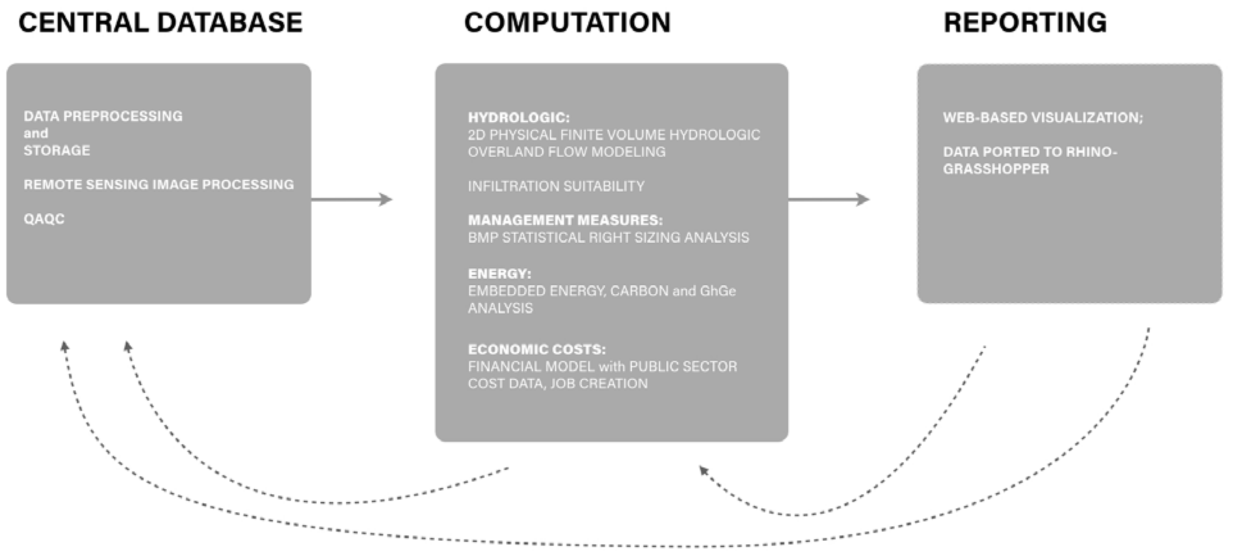

Figure: 1 Hazel 2.0 Schematic System Architecture

Task 2:
Central Database / Data Structure
Supporting the modeling system architecture requires a large and robustly curated database containing preprocessed water and land use related data designed to be fed into the computational components of Hazel and consisting of the following data:

Elevation Surfaces:
These datasets describe the topographic shape of a land surface, showing both the bare ground (known as a digital surface model) as well as the constructed and natural terrain impacted by buildings and tree canopies (digital terrain model). The City of Los Angeles Bureau of Engineering provided ALI with high-resolution LIDAR-derived elevation data, resolved to 2 ft^2 across a 200 square mile area.

Urban Fabric:
Data for describing the urban fabric's impact on stormwater includes building, property boundaries and transportation infrastructures polygons, land use, zoning, and building hazard designations, built stormwater infrastructure catchments and drainage infrastructures.

For assessing the ease at which water can potentially penetrate the urban fabric we use multi-spectral 4-band imagery processed using remote sensing techniques for deriving surface impervious indices. Latrobe funding aided in internally producing and error correcting high-resolution imperious surface datasets (resolved to 2 ft^2) across a 200 square mile area. As a result we can predict the stormwater runoff performance difference between turf grass and native grass lawns, white concrete pavements versus white crushed gravel, or ceramic tile roofs and asphaltic shingles or pavements.

For assessing potential constraining factors that *lie on the urban fabric* that could effect the safety and quality of infiltrated stormwater, we use databases from federal and state-authored environmental hazard data, such as current locations of known contaminate spills, or active environmental mitigation sites as components within the infiltration suitability computation.

Subsurface Conditions:

For assessing the infiltration ability of a given site, we need to know, at a minimum, several constraining technical factors that describe (both quantitatively and qualitatively) the ease at which water passes though a given material such as soil, gravel, sand, and rock. These factors are assessed from multiple data sources including current and historic soil surveys, surficial geology and structural geologic reports.

For assessing potential constraining factors that *lie below the urban fabric* effecting the safety and quality of infiltrated stormwater, we use databases from federal, state, and local-authored sources on environmental hazards and geotechnical conditions, such as current locations of known contaminate plumes from metallic solvents and chemical nutrients. Additionally known water supply wellhead locations as well as water quality monitoring facilities are also included. All these factors are included within the infiltration suitability analysis.

Climate and Precipitation:

Precipitation data includes both long-term historic rainfall duration and intensity, regulatory mandated storm profile / precipitation intensities, as well as date-specific precipitation storm data derived from NOAA MRMS radar imagery.

Economic Cost Data:

Central to understanding and projecting the economic costs and benefits of sizing green infrastructure, we have complied a broad list of public-sector cost data provided by the City of Los Angeles Bureau of Engineering for assessing stormwater's unit volume captured per dollar cost. This data includes both capital improvement and operations and maintenance costs for built stormwater infrastructure projects within the City of Los Angeles.

Task 3:
Model Development, Reporting / Visualization, and Expanded Metrics

Model Development: Computation Architecture
Within the system architecture, the second modeling element performs the computationally intensive routines from the preformatted data provided through the central database. The Latrobe funding advanced work in developing or refining each of the following computational sub elements:

Hydrologic Computational Engine
This sub element simulates the effects of water flowing across and interacting with the urban fabric describing the *hydrologic cycle* (Dunne and Leopold, 1978) as a series of partial differential mathematical equations (St-Venant, 1871) relating precipitation, runoff, infiltration, evapotranspiration, etc. as elements bound to the physical principles of conservation of mass and momentum (i.e. physically-based). When coupled together as “shallow water equations” they simulate the interaction between hydrologic processes above, on, and below the ground-surface (Tian, 2012). We rely on an industry established state-of-the-art hydrologic solution package for producing the detailed physically-based hydrologic results, that are then integrated into Hazel’s workflow. Please see our first report for more details.

Infiltration Suitability
This sub element assesses the safety of infiltrating stormwater into the aquifer below by assessing both ground surface characteristics and subsurface conditions simultaneously. Technically, the model uses multi-criteria decision-making techniques to identify the most suitable areas for stormwater capture, detention, conveyance, and safe infiltration. Functionally, this model is comprised of multiple components: a stormwater runoff model, an infiltration model, and a constraint model. Outputs from these three components are combined to form a resultant infiltration suitability analysis.

Management Measures
This sub element uses information from the infiltration suitability analysis [above] to assess, out of a menu of USEPA and Los Angeles County approved approaches, the most appropriate stormwater management practice or BMP for any 10,000 ft^2 area (a regulatory-mandated threshold) within our modeled 200 square mile domain.

Embedded Energy
This sub element calculates using a modified life-cycle approach the whole or “actual” cost of energy conserved or expended as a result of infiltrating stormwater on a per unit volume basis. By comparing the whole energy costs and energy density of providing the same volume of imported water for each volume of infiltrated stormwater, we can predict both the energy savings and its related carbon footprint costs for the more localized water supply solution of stormwater.

Economic Impacts Component
This sub element calculates an estimated cost for constructing and maintaining both green and grey stormwater infrastructures identified within the Management Measures sub element.

Note: We initially planned within the research application to develop an ecosystems services module as another component of the overall modeling enterprise and completed some initial scoping work, however due to resource limitations implementation was not possible.

Reporting / Visualization
Within the third element of the Hazel system architecture results are reported and visualized within a web-based interactive 3D environment. We feel this design visualization approach will supports users in by serving as a bridge and catalyst between the quantitative objectives (produced within the Computational Element) and the qualitative concerns more typically shared from the design audience, community and public.

Expanded Metrics
Latrobe partners worked together to define and expand Hazel's capacity to measure the interaction between built environment, water resources, energy systems, and economic impacts. We were able to develop and integrate the following metrics into the modeling enterprise for allowing designers to introduce proposals onto a given site and assess their scenario-based performance.

<u>Stormwater infiltrated</u>:
Units: gallons, or acre-ft
Volume of stormwater infiltrated by gravity through the urban fabric and into soil and subsequent underlying geologic layers for storage during a 24-hr period for a given storm intensity. Infiltration volume is also estimated on an annual basis from long-term precipitation records and last recorded year.

<u>GHG Reductions</u>
Units: (tons of CO_2)
GHG definition: Greenhouse gases [GHG] absorb infrared radiation thereby trapping heat and making the planet (or closed system) warmer (EPA, 2017). Carbon dioxide (CO_2) is used as a greenhouse gas "metric" for determining the relative warming impacts caused by other greenhouse gases such as methane (CH_4), nitrous oxide (NO_2) and others. (IPCC, 2014). For evaluating the potential GHG reductions for utilizing stormwater, we calculate, based on the volume of stormwater infiltrated, an equivalent volume of imported water together with its well-understood embedded energy component. This energy represents the work needed to convey, pump, and distribute an equal amount of raw imported water, expressed in kilowatt-hours per unit water volume. We calculate the carbon footprint of this electrical energy two ways: (1) based on the 2015 national mean GHG emissions per kWh from the electrical energy production sector, and (2) using the State of California's mean electrical generation GHG emissions.

<u>Energy and Water Interconnection</u>
Units: (kWh, and acre-ft)
Using the *WERCM*: water and energy resource characterization modeling approach, developed by Rowan Roderick Jones, we can calculate four interconnections between water and energy:

- *Energy in Water*: Whole-cost accounting approach calculating the amount of energy required for conveyance and distribution of a unit volume of untreated (raw) imported water supply;

- *Energy in Energy*: Estimation of the amount of energy lost through system inefficiencies such as production and transmission losses specific to the energy-in-water requirement from above.

- *Water in Water*: Estimation of the amount of water consumed or lost through the production of an imported supply such as leaks, evaporation, seepage, breaks within distribution mains, etc.

- *Water in Energy*: Estimation of the volume of water lost through the production of a given unit of energy (tied to the energy requirements of the energy-in-water value).

Economic Costs

Units: dollars expended

Using data complied by the City of Los Angeles Bureau of Engineering for multiple built projects within the City, we evaluated the mean costs for five stormwater best management projects [BMPs]. These mean costs include the unit public-sector base cost for construction and annual operational and maintenance costs, and have been complied for the following structural and nonstructural (green) stormwater infiltration devices:

Dry Wells [gray infrastructure];
Infiltration basin (scaled for private land use) [gray infrastructure];
Porous and Permeable Pavement [gray infrastructure];
Tree Box Filters [green infrastructure];
Vegetated Swales [green infrastructure] (figure 2)

Typical design, permitting and other soft costs are estimated as a percentage of the capital base costs. While published databases exist for determining a majority of BMP costs (the USEPA has published BMPs construction costs using a “twenty-city average” and requires further regional adjustment factors to use the data within the western US (USEPA, 1999)), however, to date there is little evidence for published data on public-sector costs specific to the western US and more specifically Los Angeles.

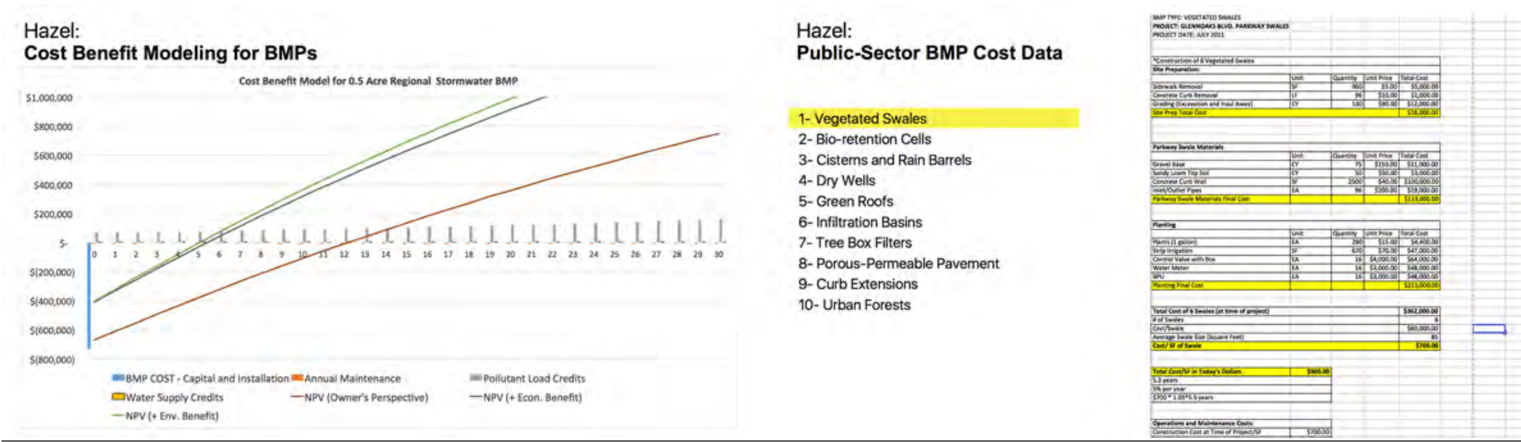

Figure 2: Economic Costs from Public-Sector BMP data, City of Los Angeles Bureau of Engineering [right], and Cost/Benefit Financial Modeling for BMP, Rowan-Roderick Jones [left]

Financial Payback Period and Jobs Created

Units: dollars / time and number of jobs

The financial modeling component of the tool allows measurement of the capital base costs for stormwater green and grey infrastructure along with annual operations and maintenance costs (determined from module above) across a 10 to 20 year duration (figure 2). Once Hazel has completed specifying the menu and size of the decentralized stormwater infrastructure, a net present value financial framework for assessing the potential multiple benefits and cost factors such as pollutant load credits, jobs creation, impacts to local tax revenues, rate of return on investment, etc. over the course of the long-term project duration. Although some of the potential benefits are policy reliant and have only been adopted sporadically across the nation, for example stormwater pollution credits or water production credits as offset from imported supply, the future of monetizing green stormwater infrastructure remains viable despite a (temporary) federal derailment.

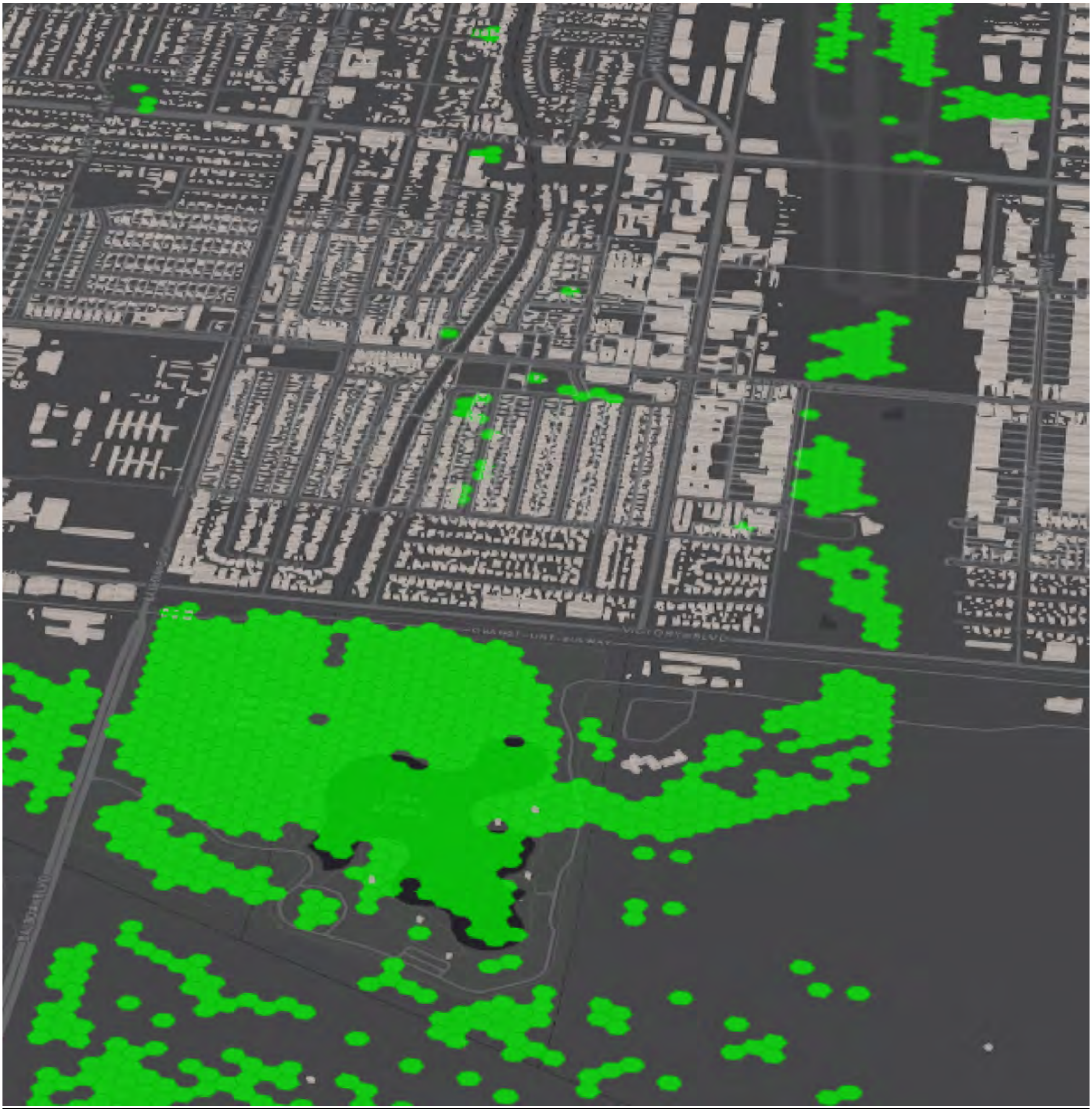

Figure 3: Hazel @ Work: Finding Optimum Infiltration Sites within Large Urban Watersheds.

Task 5

Information Synthesis:
Improving Decision-Making and Identification of Hydrologic-based Zoning

Hazel's coupled surface/subsurface analysis approach identifies multiple stormwater capture opportunities, improving decision-making when examining the impacts of performance-based hydrologic zoning across multiple scales.

Subsurface Data and Analysis

Looking beneath the density and complexity of the existing urban surface, Hazel provides insight into subsurface conditions necessary to safely and efficiently infiltrate stormwater.

Hazel's subsurface infiltration model processes and analyzes multiple soil and geotechnical layers.

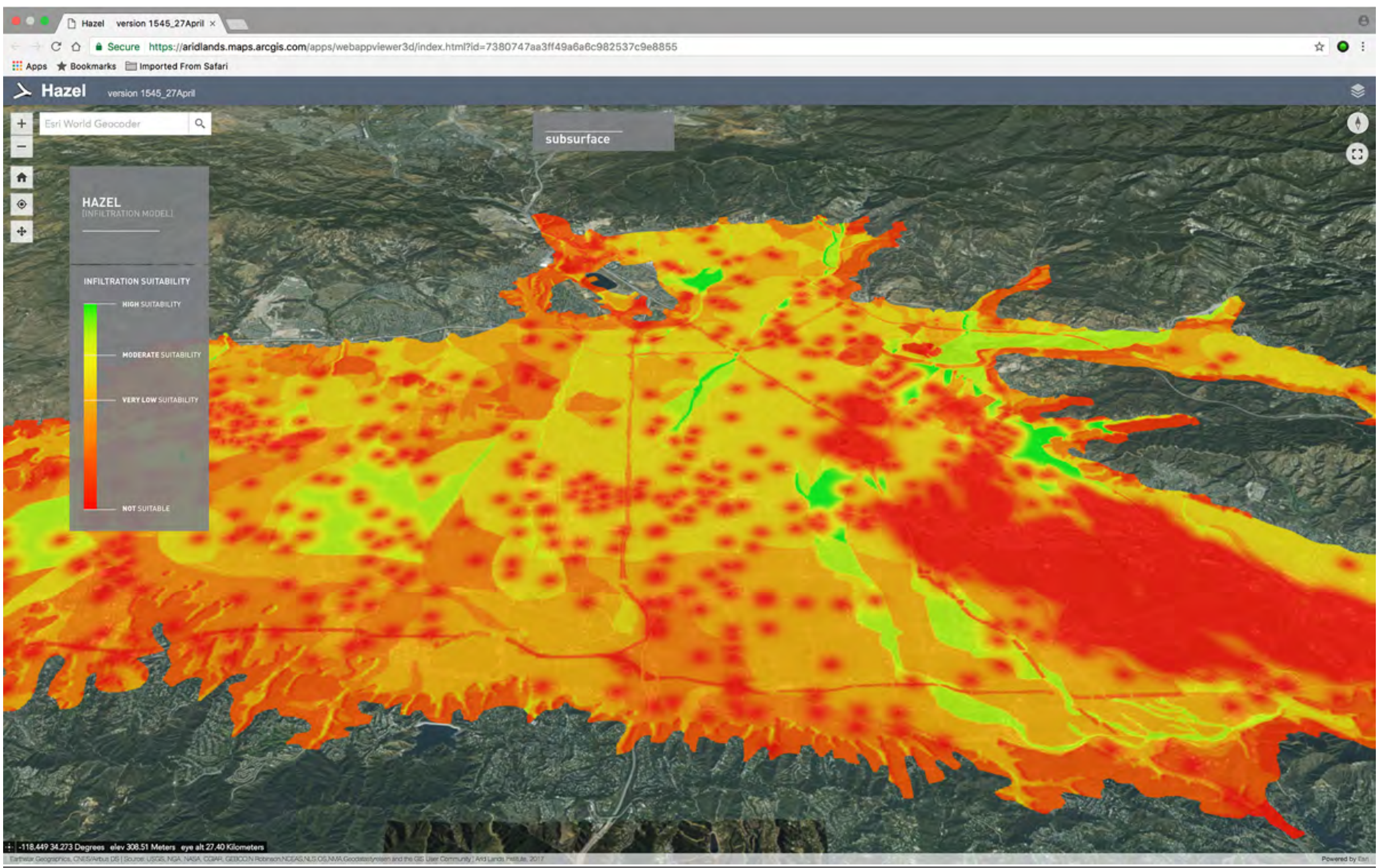

Figure 4: Hazel subsurface infiltration suitability across a 200 mi^2 study area.

The results show the suitability levels of draining water through a given soil layer—(determined by hydraulic conductivity and adjacency to known subsurface risks). By including subsurface risks---liquefaction zones, contamination sites (from large Superfund sites to tens of leaking gas tanks)—Hazel constrains the infiltration opportunities, and assigns them values. This allows the user to locate infiltration opportunities and weigh them against potential risks to water quality, given the user's objectives and risk-tolerance levels.

Surface Data and Analysis

Hazel then combines its subsurface assessments with surface analysis. Impervious surfaces (pavements, compacted earth, tile roofs, etc.) largely control the volume of stormwater runoff generated and effect the quality and quantity of stormwater generated (Arnold et al, 1996). Understanding their make-up is critical for fine-tuning green infrastructure response at both large and small scales.

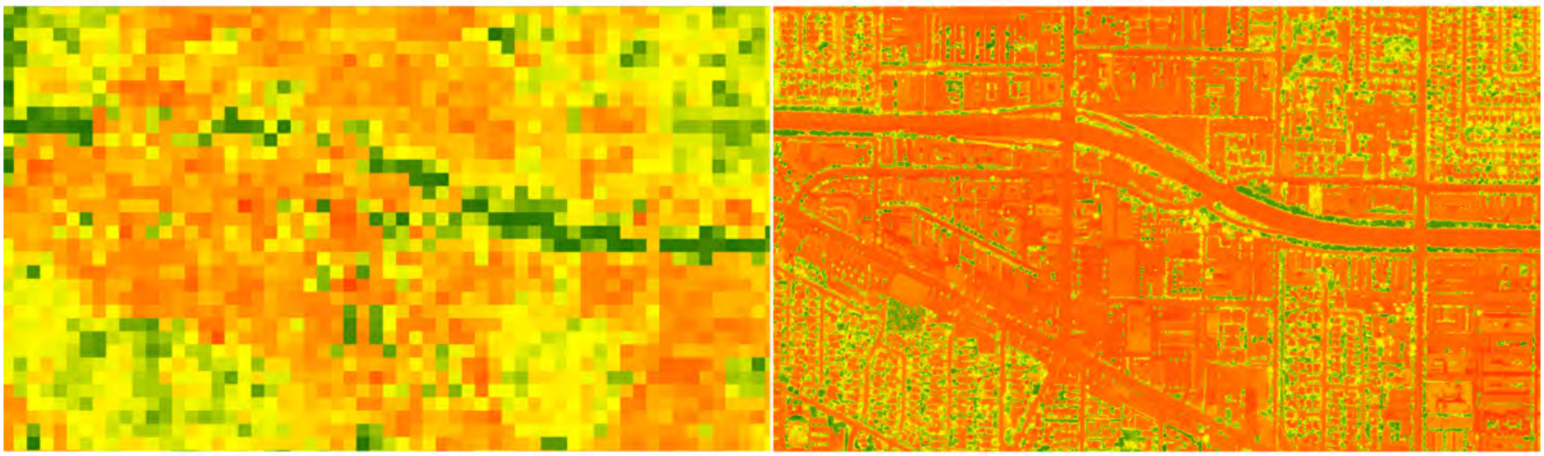

Figure 5: Hazel 1.0 impervious surface dataset (15m^2 / pixel) [left], Hazel 2.0 impervious surface dataset (0.609m^2) [right]. Note same coverage area for left and right images.

Hazel computes the percentage impervious surface at a very high resolution (0.609m^2 or 6.5 ft^2) using peer-reviewed methods for characterizing and processing remotely sensed imagery. Unique to the Latrobe work was the development of a semi-automated process to both create a high-resolution impervious surface dataset using RGBIR training data as well as to provide initial quality and data assurance review . Hazel 1.0 impervious urban surface dataset was resolved to 15m^2 (approximately 161 ft^2)—with Latrobe support, we were able to acquire new higher resolution training data and resolve to 6.5 ft^2 —providing an unprecedented level of access to precise surface conditions effecting stormwater run-off (figure 5). Use of this new information can allow for more precise design solutions to be tested, evaluated, and prioritized; this data, at its current high resolution, has not been previously accessible to architects and designers.

Additionally, Hazel interprets surface permeability, slope, and land uses to guide the user on whether surface conditions (how much runoff can I capture?) align with subsurface conditions (is this an appropriate place to infiltrate?).

Coupled Surface and Subsurface Decision-Making: What is Hazel Telling Us?

Coupling surface with subsurface data allows users to optimize their decision-making. Knowing both the biophysical constraints (below grade) and the most plentiful or advantageous opportunities (above grade) guides the user on where to most effectively deploy appropriate green infrastructures.

The result is accelerated, high-precision decision-making, whether working at a site scale, a municipal scale, or a basin scale, for optimized watershed health.

Emerging Hydrologic Zones

If we look at Hazel's visual analysis of a basin or a city or a site, we see three basic zones emerging. Every site is characterized within a spectrum of zones: Hazel zone 1: Infiltrate Here; Hazel zone 2: Combination of Capture and Distribute; Hazel zone 3: Capture and Store on Site (infiltration is not supported). For each zone, this script automatically suggests a small catalog of BMPs suited to the surface and subsurface conditions. The inventory of BMPS is derived from EPA data and protocols. Each zone is ranked or prioritized for suitability, gradated along a spectrum of risk/reward, and tied to a catalog of appropriate BMPs.

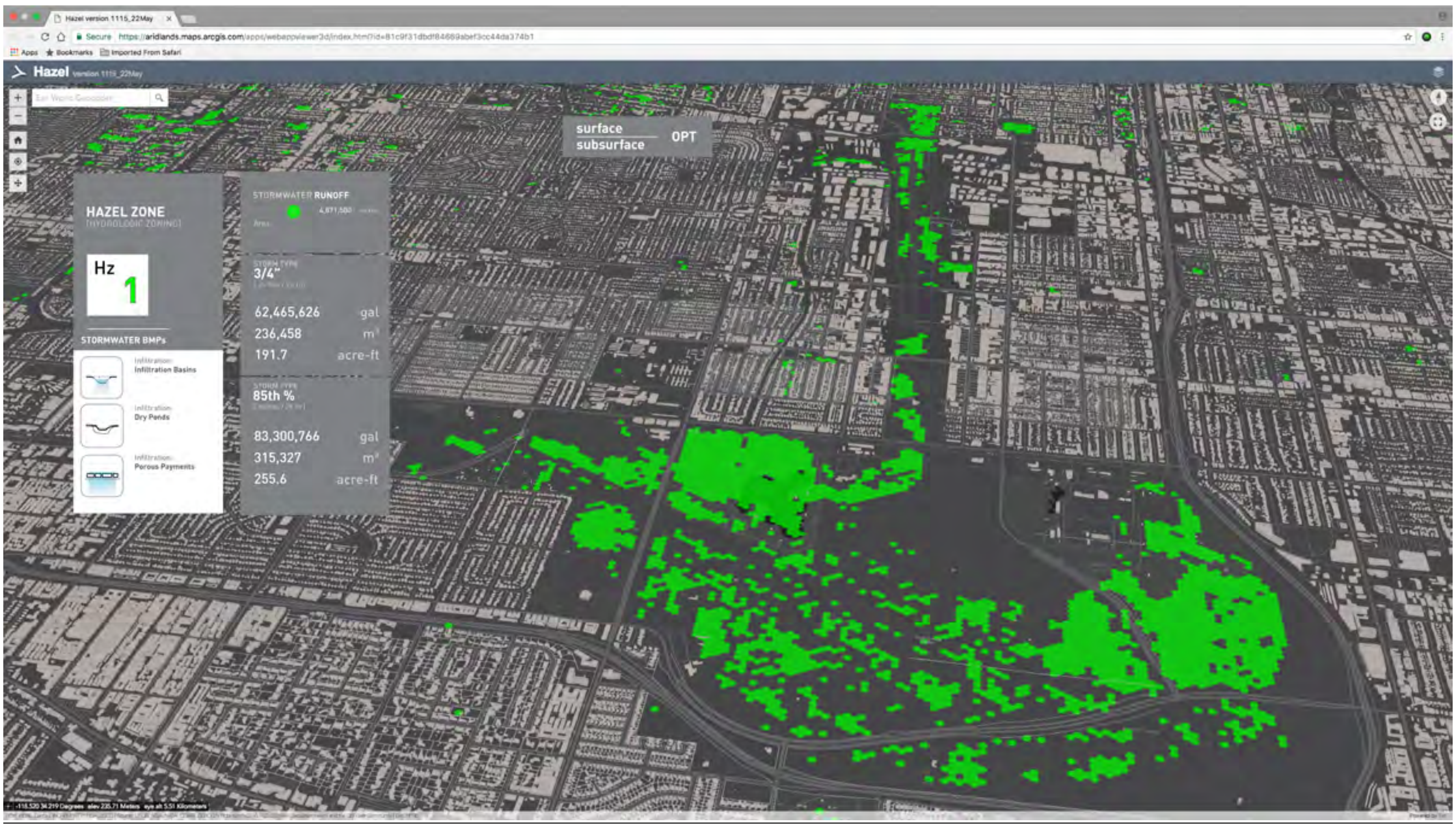

Figure 6: Locations of Hazel Zone 1 within an urban watershed.

Hazel Zone 1: Infiltrate here.

This is the zone most appropriate for green and grey infrastructures designed to infiltrate stormwater efficiently, rapidly, and cost-effectively. It represents the ideal interconnection between pervious urban surfaces and safe and well draining subsurface conditions. Within this zone there a relatively small threat of infiltrated stormwater to transport subsurface chemical impairments into receiving aquifers or extraction wells. Because of these interconnections, this zone also represents the least expensive location for implementing infiltration-based stormwater BMPs as measured in the levels of surface / subsurface preparation necessary to achieve safe infiltration. The most appropriate best management approaches or practices include infiltration basins, dry wells, and porous pavements. Hazel identifies and assists in placement within the landscape of the most suitable stormwater best management practices, indicated as green hexagonal symbols, with each symbol demarcating an area of approximately 10,000 ft^2 (figure 6).

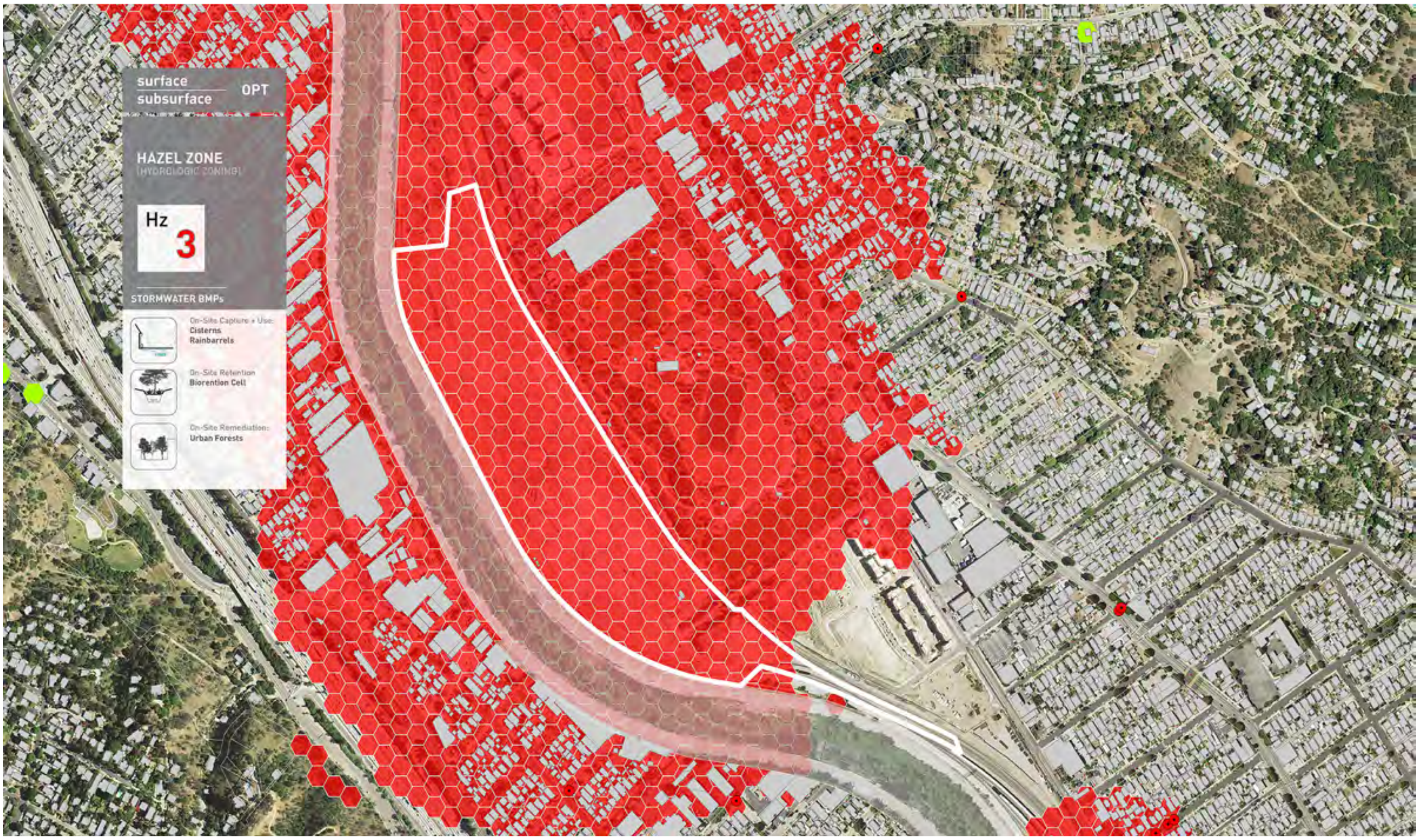

Figure 7: Locations of stormwater management opportunities within Hazel Zone 3 at neighborhood scale.

Hazel Zone 3: Capture and On-site Reuse.

On the opposite end of suitability is **Hazel Zone 3** (figure 7). Infiltration is not advisable in Hazel Zone 3 –either because of geology, contamination, or other risk factors. Hazel Zone 3 suggests that stormwater be captured, contained, and reused on-site—potentially the most expensive stormwater retention practices. Stormwater best management practices within this zone include:

On-site capture and reuse from cisterns and rain barrels;
On-site retention;
and
Urban forests (as an effective remediation strategy and carbon sink).

Figure 8: Locations of stormwater management opportunities within Hazel Zone 2 at neighborhood scale. Hazel provides BMP prioritization: darker yellow hexagonal markers indicate areas of higher priority (less expensive capital costs due to improved surface and subsurface conditions as compared with areas of lighter yellow markers.).

Hazel Zone 2: Hybrid Infiltration Strategies.

Hazel Zone 2 is moderately appropriate for infiltration (figure 8). A hybrid approach is appropriate here: some on-site capture and re-use strategies in combination with capture and conveyance to more appropriate Hazel Zone 1 infiltration sites. Stormwater best management practices within this zone include:

On-site capture and reuse from cisterns and rain barrels;
Stormwater-smart streets: curb extensions and porous pavements;
Dry ponds
Infiltration basins;
and
On-site retention using bio-retention cells.

When we zoom in from basin to lot scale, we can see each hexagonal tile represents approximately 10,000 ft^2. Whether publically or privately owned, each hexagon is characterized for relative infiltration suitability.

In the public right of way, Hazel gives agencies more room to prioritize and allocate resources. If my agency is considering a billion dollars in repairs over hundreds of miles of sidewalks, where should I invest in permeable pavers? What will they cost me? What will I gain?

Hazel provides feedback.

Costs, benefits, and impacts of stormwater capture vs. importation are well understood and measurable in terms of gallons of water infiltrated, treated or stored; kwh of energy expended; tons $C0_2E$ emitted. Using prevailing wage and per-unit capital cost data provided by City of LA Bureau of Engineering, and payback timelines generated in collaboration with Rowan Roderick Jones of the Nature Conservancy, Hazel users can look at job creation and construction, maintenance, and operation costs and evaluate green infrastructure investments in the context of water, energy, carbon, and economic objectives.

When overlaid with other, independent GIS layers---such as demographics, income and employment levels, park poverty, or other infrastructural investments (transit or housing, for example)--users can evaluate and prioritize green infrastructure investments in the context of social equity and environmental justice objectives.

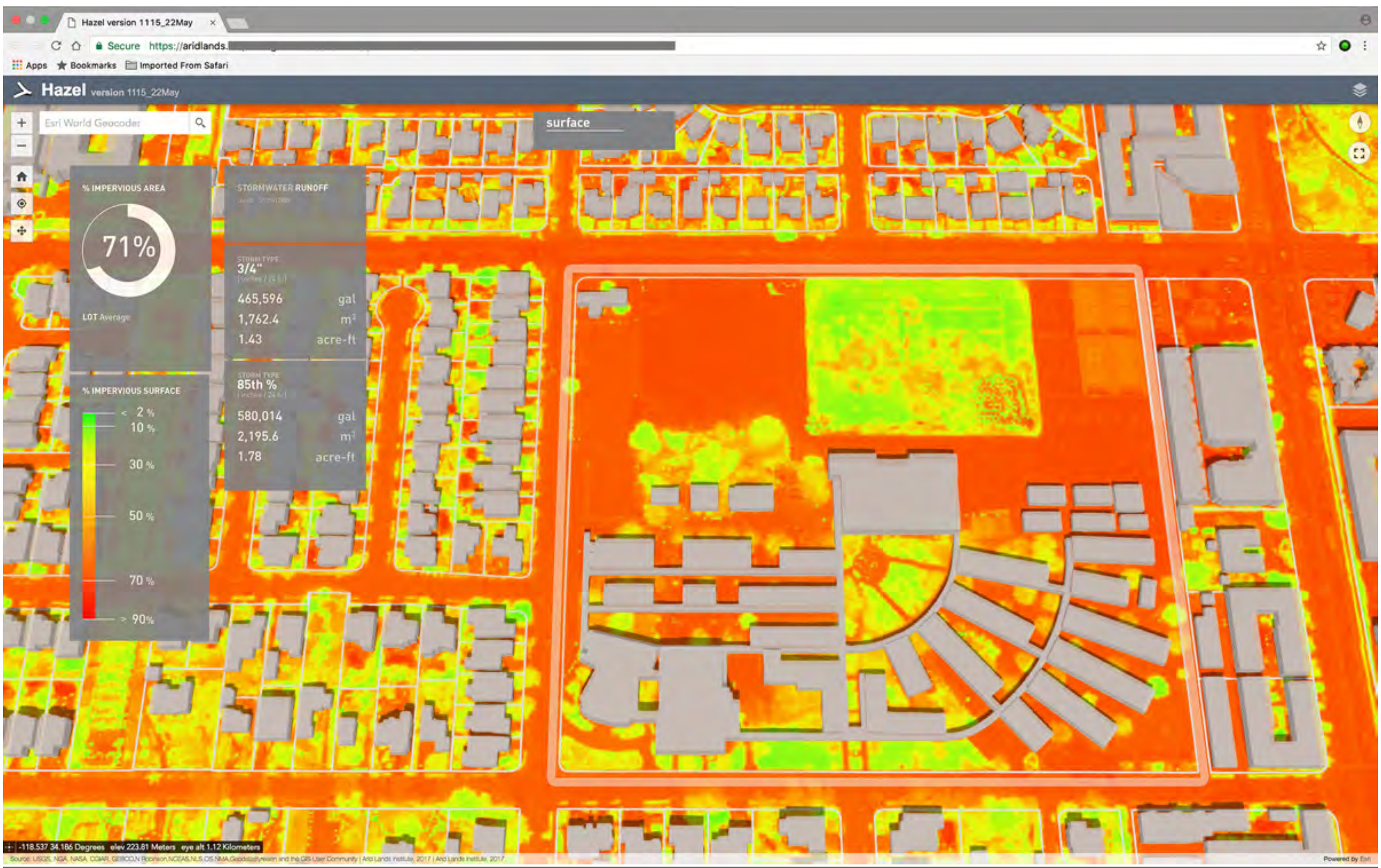

Figure 9: Hazel Impervious Surface Analysis at the building parcel / lot scale.

At the lot scale, questions are comparable.

What do I have to do to get my building to comply/align with stormwater / LID regulatory requirements (and anticipated future --more aggressive-- regulations)? Given my site's surface and subsurface conditions, what are my options? What are they likely to cost me? What are the likely gains? How can I explore more choices earlier in the design process?

Iterative Updating and Feedback

Specific to the reporting element within Hazel's system architecture, Perkins+Will team members [Justin Brechtel, Leigh Christy, and John Haymaker] with Rowan Roderick-Jones of the Nature Conservancy developed a Grasshopper user interface that ingests Hazel databases and modeling outputs allowing designers to quickly see the regulatory and economic implications of their design choices within a single building parcel or lot. This approach, leveraging Hazel's infiltration prioritization modeling output to advance the understanding and uncovering of a sites particular hydrologic interworkings, is innovative and to our knowledge does not currently exist within the marketplace. Once Hazel data for a particular site is ingested into the interface, users begin their schematic design process. The grasshopper script provides interactive feedback assessing the design's impacts (location and performance) in meeting regulatory stormwater runoff requirements tied to estimated capital cost implications (cost data was provided by the City of Los Angeles Bureau of Engineering [Deborah Weintraub, Katherine Doherty, and Kendrick Okuda]).

The system architecture diagram for the grasshopper interface w/ Hazel (figure 10): ingestion of Hazel geodatabases and modeling outputs (left), grasshopper scripted user interface (center), and output results (right) in multiple formats. Iteration allows adjustment to scheme.

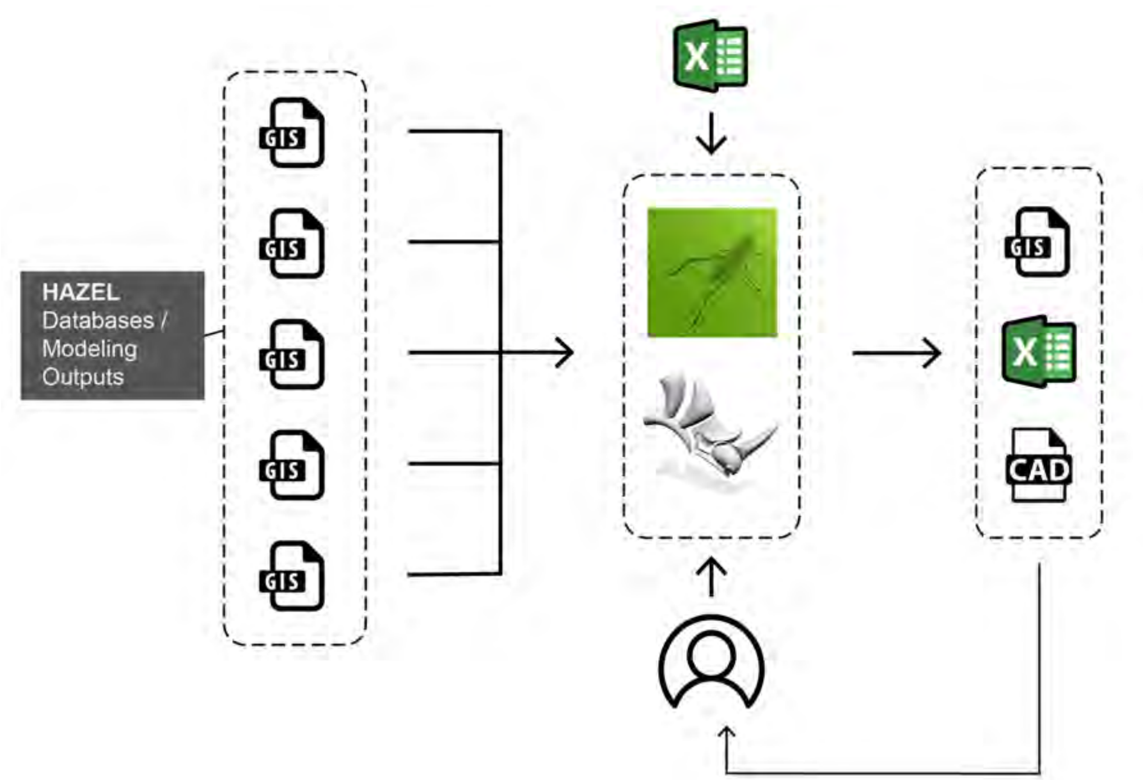

Figure 10: System Architecture for Evaluating Iterative Design of Stormwater BMPs (Perkins+Will)

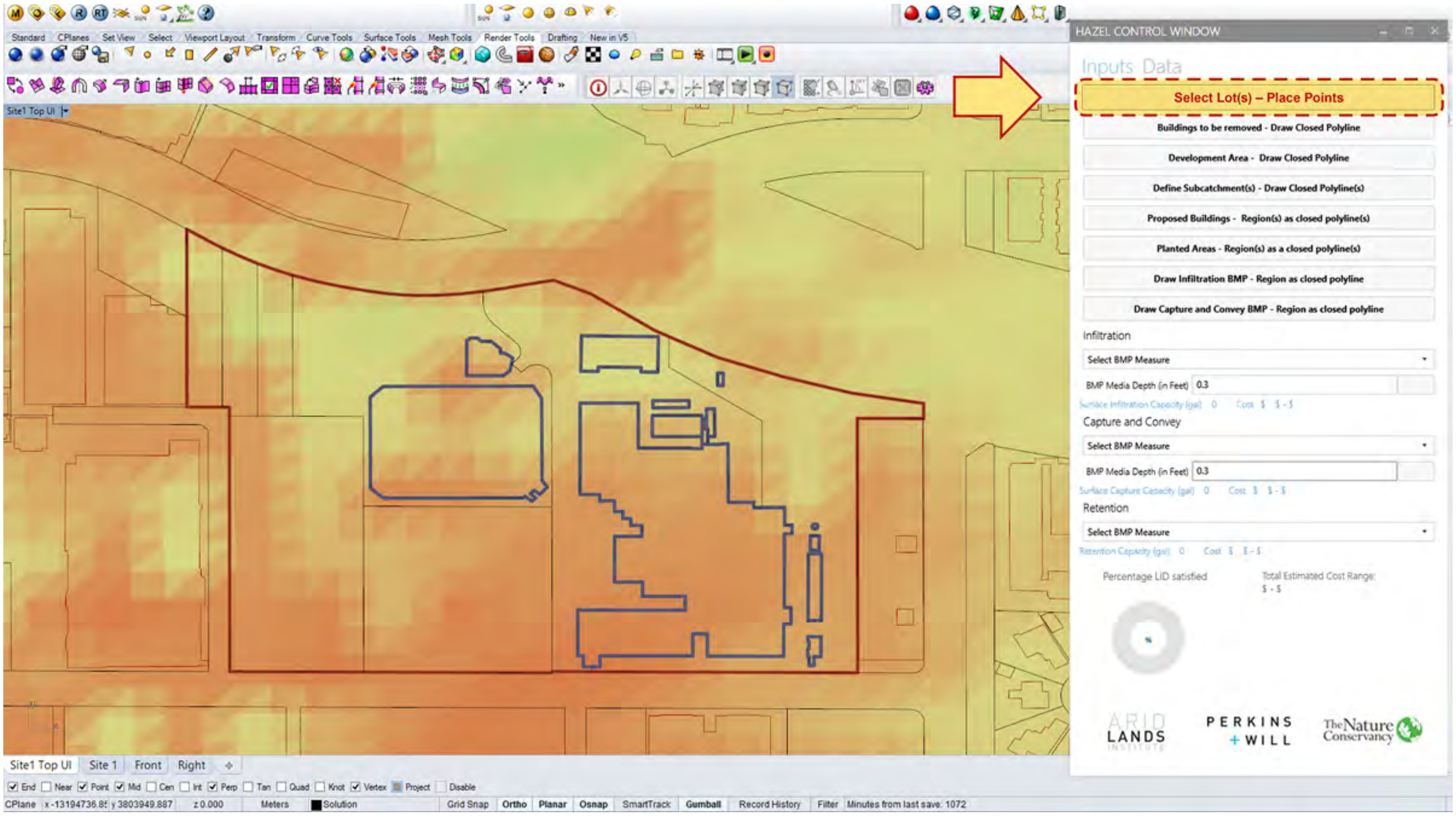

Figure 11: Hazel infiltration score and lot selection. (Perkins+Will)

Following the initial ingestion of Hazel's geodatabases and modeling outputs, areas that offer the highest strategic value for infiltration are shown colorized by zone type: Hazel infiltration zone 1 in green (no areas present within selected lot,) Hazel infiltration zone 2 in yellow, Hazel infiltration zone 3 in red/orange. Users are then led through a series of input prompts for selecting and defining the specific area of intervention (figure 11).

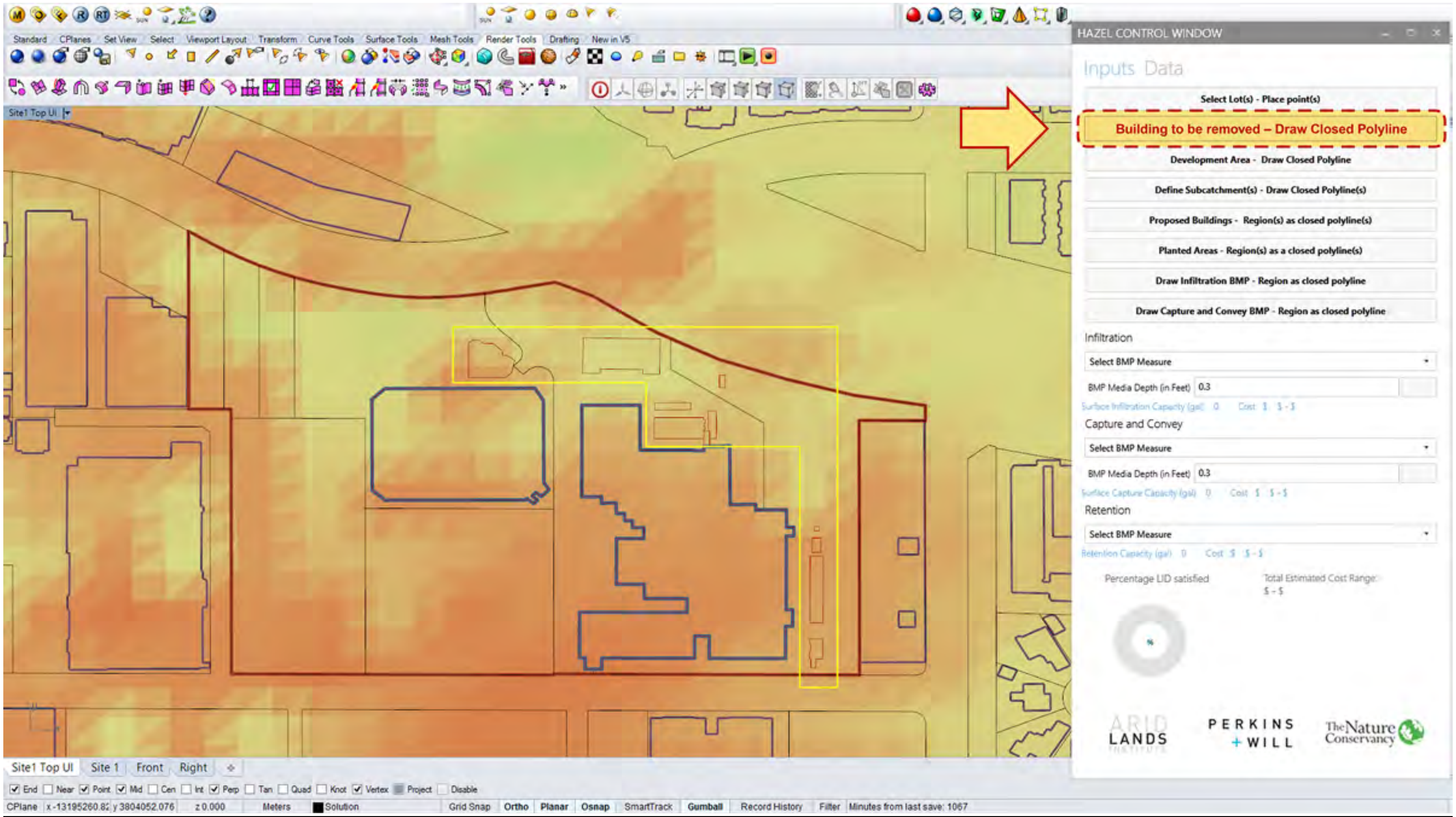

Figure 12: Existing buildings slated for removal. (Perkins+Will)

As part of the schematic design process users can select and adjust a site's existing conditions by removing buildings. Once removed, their impact to stormwater production is reevaluated within the script (figure 12).

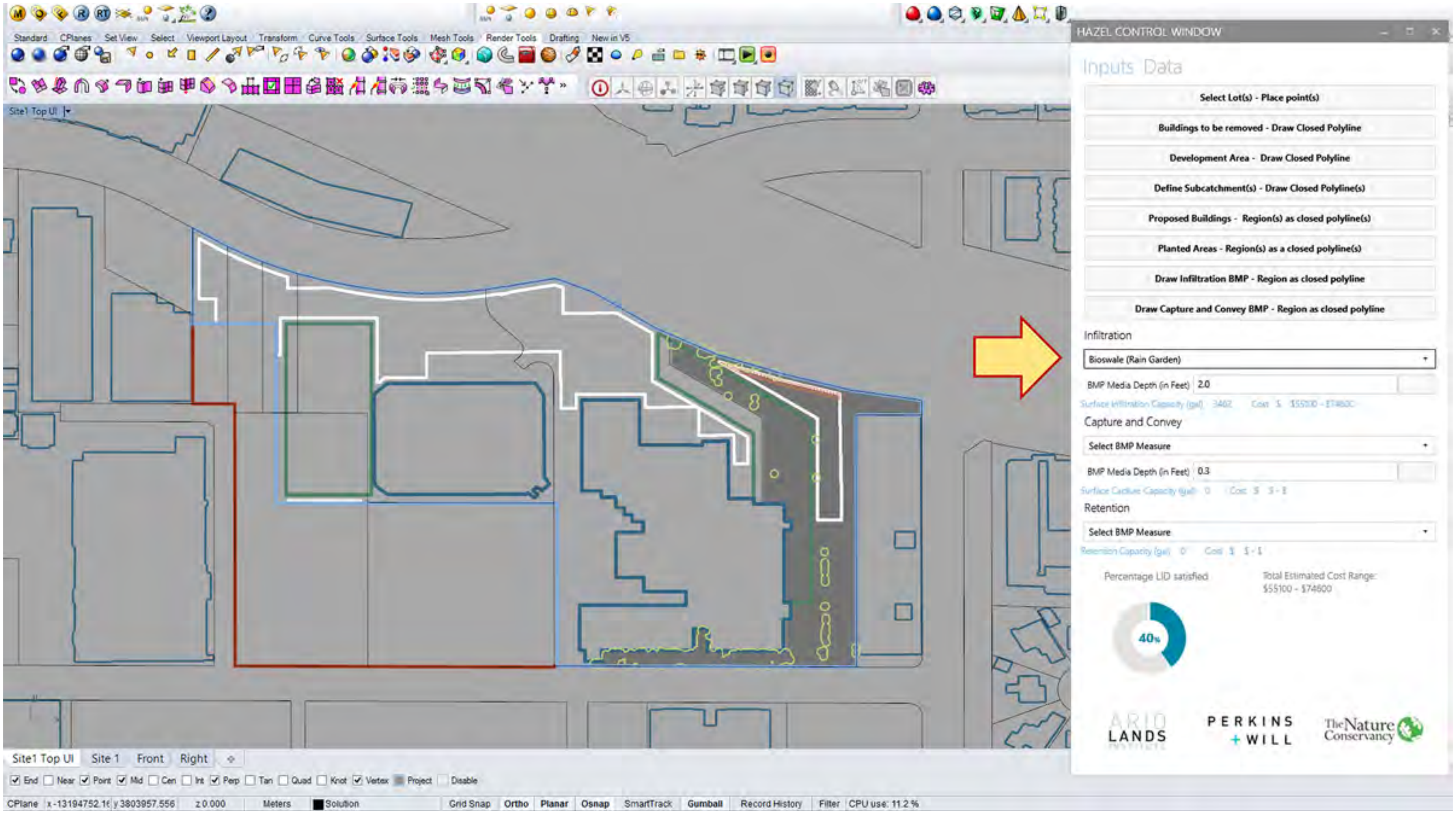

Figure 13: Design strategy for initial stormwater BMP. (Perkins+Will)

Following input of an initial site design with stormwater BMPs placed and specified, a runoff assessment is calculated. Within the example (figure 13) the initial schematic design is not wholly sufficient to meet regulatory mandated stormwater runoff requirements —only 40% of the generated runoff is accounted for within the design scheme. This can be attributed to several design-related parameters such as location and placement within the site, capture size and area, and BMP typology, or a combination thereof. Once an initial runoff assessment is calculated users can reconfigure the design and reassess to achieve regulatory compliance with stormwater runoff volume.

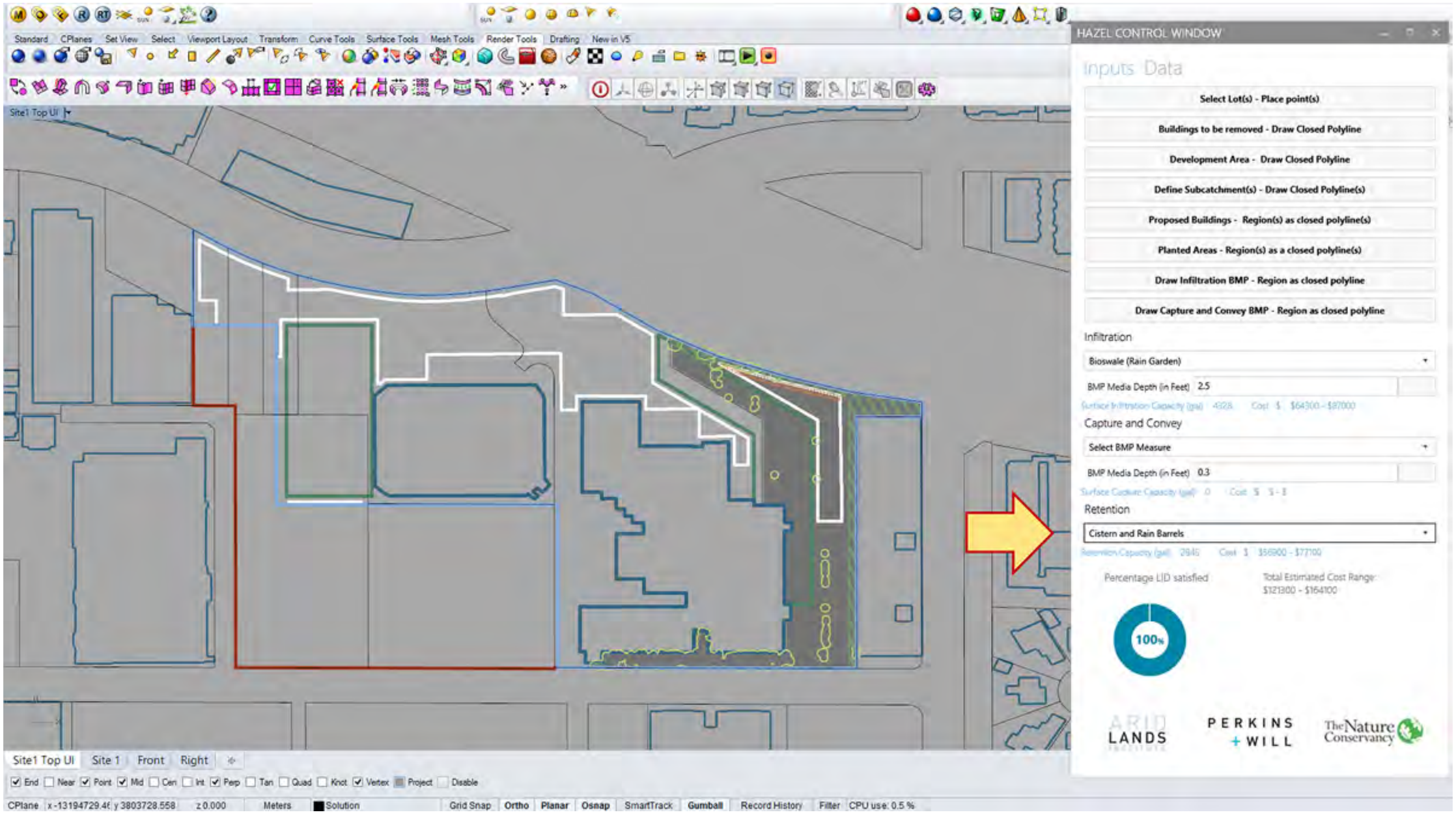

Figure 14: Specification of stormwater BMPs (Perkins+Will)

With each iteration of BMP selection users understand the percentage of stormwater volume retention / detention compliance for a given design scenario tied to estimated capital costs for compliance. If the schematic design constrains the required surface area within a project for stormwater BMP placement, the script identifies any unmet stormwater volume and assigns that portion of runoff to on-site detention using cisterns and rain barrels with detained stormwater offsetting on-site irrigation needs (figure 14.)

Workshop Testing Sessions
Workshop 1

Figure 15: Workshop 1, in-house trial at Perkins+Will, Los Angeles, March 2017.

For assessing the performance and usability of the Hazel toolset, Perkins+Will played the lead role in the internal testing phase, with both in-house trials and structured workshops for invited professional design teams working on selected demonstration sites. Workshop 1 was conducted within the Los Angeles office of Perkins+Will using an active project 40-acre office park development to evaluate the Hazel tool's performance.

<u>Summary of Workshop 1:</u>

A summary of comments from participants included:
"[Tool] Gives ability to check Civil Engineer" "…Explore scenarios, options, alternatives…"
"Scope of magnitude of challenge and problem definition up front"
"Cost data very valuable"
"Power of data - lots of it in one place - FAST"

Potential Cost Savings, from Workshop 1

As part of the workshop trials, we gathered cost and time-usage data from the team members for assessing how much time is required to typically address stormwater compliance issues within the firm on a project basis. We present the results below.

We found that use of the Hazel tool could provide significant cost savings. Results from less than 1 hour of tool use saved an equivalent percentage of 2-4 months of work time across multiple consultants. We conservatively estimate this cost savings as ranging from $6,700, for small-scale projects and < $11,000 for larger projects.

SUMMARY: Time and Cost Devoted to Solving Stormwater Capture Projects, Los Angeles			
Team:	**% Total Time Allocated to Addressing Stormwater Requirements**	**Small Project Costs:** 15% FTE for 2 months * (% Time Allocated for Stormwater ONLY)	**Large Project Costs:** (15% FTE for 4 months) * (% Time Allocated for Stormwater ONLY)
1 Architect, associate	100	$ 1,865	$ 3,730
1 Architect, Project Designer	30	$ 616	$ 1233
1 Architect, Project Architect	20	$ 363	$ 727
1 Civil engineer, associate	100	$ 3,934	$ 5,901
Sum, Small Project:		**$ 6,779**	
Sum, Large Project:			**$ 11,590**
*FTE Cost Source: glassdoor.com, June 2017; FTE required time: Perkins+Will, Feb 2017			

Table 1: Hazel Cost Savings by Project Size

Workshop Testing Sessions
Workshop 2

Figure 16: Workshop 2, public trial at LACI: Los Angeles Cleantech Incubator, March 2017.

Each workshop was designed to gather user feedback on the tool usability. We measured this feedback through survey instruments distributed following the conclusion of the workshop. To simulate actual working conditions within a firm, participants were given a site and over the course of an hour were asked to solve, by hand, its unique stormwater compliance issues. At the conclusion of the hour interval, the DRI team then presented the Hazel tool and asked participants to solve the site's runoff requirements digitally. A bottle of fine French champagne was offered as an incentive to the team that not only met the stormwater requirements, but did so as inexpensively as possible. Below are the overview comments following the conclusion of the workshop and a summary of the survey instrument.

<u>Overview, Workshop 2:</u>
"Likely to accelerate significantly more exploration in much shorter time"
"Good tool for decision-making at planning stage"

“More time could be spend exploring design option rather than spent on calculations and research”
“Hazel allows for quick analysis of a site early on without needing extensive background on the subject”

Metrics translated into meaningful units:
Gallons Stormwater infiltrated by green infrastructure [GI] translated into Household/per year equivalents;
GHG translated into cars/emissions per year equivalents;
GI translated into habitat and proxy for heat-island reduction assessment;

Summary Survey Results, from Workshop #2

Survey Results
Hazel Workshop #2, March 04, 2017

	Category	Findings / Summary	Notes
Overall	Assessment of Design Value	**87.5%** (7/8) **positive responses.** [61.5% (8/13) response rate]	Users enjoyed being able to get quick data without extensive input. The only criticism was focused on the need to see the overlay of hexagons to site.
	Impact on Design/Decision Making Process	**85.7%** (6/7) **positive responses.** [53.8% (7/13) response rate]	Users enjoyed the enhanced accuracy and ease of estimation. One user found that it would change their team's working process by allowing them to be involved in the design process earlier. The only critical response focused on the narrow focus forced by the tool.
	Assessment of Ability to Address Obstacles in Current Practice	**75%** (3/4) **positive responses**. [30.8% (4/13) response rate]	Respondents seem to have had difficulty answering the question.
	Desired Additional Features	**Inconclusive.** [30.8% (4/13)) response rate]	All respondents had different suggestions.

Design	Design Process: Hazel impacts	**100%** positive responses. [38.5% (5/13) response rate]	Users appreciated the ease-of-use, accuracy and quickness of the tool.
	Design Process: Hazel impacts on Internal Team	**100% positive responses**. [38.5% (5/13) response rate]	Users had varying responses as to which member of the internal team would be impacted. All felt the internal team would be beneficially impacted by the use of Hazel within the design process.
	Design Process: Hazel impacts on External Team	**66.6%** (2/3) felt that the external team would be beneficially impacted by the use of Hazel. [23.1% (3/13) response rate]	

Survey Results
Hazel Workshop #2, March 04, 2017

	Category	Findings / Summary	Notes
Time Requirements: Site Design	Time: Impact, hours spent related to site design by Internal Team	**100%** of the respondents that answered felt that Hazel would impact the number of hours the internal team spent on site design. **50%** felt that Hazel would increase the hours spent on site design by the internal team and **50%** felt that Hazel would decrease the hours spent on site design by the internal team. [15.4% (2/13) response rate]	
	Time: Impact, hours spent related to site design by External Consultants:	**50%** of the respondents that answered felt Hazel would have an impact. 50% of the respondents that answered felt **Hazel would decrease the number of consultants that would have to be hired.** [15.4% (2/13) response rate]	

Time Requirements: Stormwater Design	Impact, hours spent designing for stormwater capture by **Internal Team**	**100% of those that answered felt Hazel would increase the amount of time that could be spent on design options.** [7.7% (1/13) response rate]	

Meeting / Exceeding Incentives	Mandates/Regulatory Compliance	**100%** of respondents that answered the question felt that there would be a positive impact. [15.4% (2/13) response rate]	
	Client's Wishes/Qualifying for Rebates/Incentives	**100%** of respondents that answered the question felt that there would be a positive impact. [7.7% (1/13) response rate]	
	Competitive Edge	**100%** of respondents that answered the question felt that there would be a positive impact. 7.7% (1/13) response rate	

Survey Results
Hazel Workshop #2, March 04, 2017

	Category	Findings / Summary	Notes
Team's ability to articulate stormwater objectives	How objectives are understood/communicated to clients and consultants	**100%** of respondents that answered the question felt that there would be a positive impact. [7.7% (1/13) response rate]	
	How alternate objectives and paths to meeting them are explored	**100%** of respondents that answered the question felt that there would be a positive impact.	
Impact on user ability	To analyze/predict/evaluate design outcomes	**100%** of respondents that answered the question felt that there would be a positive impact. [7.7% (1/13) response rate]	
	Confidence in design decision making	**100%** of respondents that answered the question felt that there would be a positive impact. [15.4% (2/13) response rate].	
	Communication of design rationale	**100%** of respondents that answered the question felt that there would be a positive impact. [7.7% (1/13) response rate]	
Assessment of Hazel Operability		**25%** of respondents that answered had a positive evaluation. **75%** of respondents offered a partially positive evaluation with suggestions. [30.8% (4/13) response rate.	

Table 2: Workshop 2 Survey Summary

Task 7:
Decision-Making and Policy Impacts

Public-Private Partnerships and Healthy Credit Markets

Hazel and the type of thinking that has gone into it can be used to seed policy and implementation at regional levels and across broader geographies. This can be accomplished through current policy changes underway within the stormwater management space.

Hazel is working at a crossroads of need and activity. It can help to shape the path that municipal stormwater managers take, ultimately influencing how architects and urban designers are thinking about the impacts of their site designs.

There is no direct incentive for cities and property owners to manage their stormwater if it weren't required, but it is. Over 700 cities in the US face legal action by the USEPA in various forms with regard to stormwater runoff. These issues might be compounded by combined sewer overflow consent decrees, total maximum daily load [TMDL] Clean Water Act program mandates, or actions related to breach of National Pollutant Discharge Elimination System [NPDES] permits, etc.

So while the USEPA has historically mandated better stewardship of stormwater, which is aimed at healthier waters, there's a huge need for capital to achieve compliance. In fact, there's over $100 billion of need just to fix aging stormwater infrastructure in the US. Based on work completed at the Nature Conservancy we estimate that if the role of green infrastructure were to fix just 20% of the nation's stormwater management needs, it could require somewhere in the realm of $20 billion per year of investment for the next 20 years.

Stormwater Policy Trend 1: Meeting a Growing Funding Gap

Many cities are cash-strapped and, unlike water supply or agriculture, there's very limited federal funding supporting stormwater management. In some cities water utilities enact and collect stormwater fees either as a subset of sewer fees or based on the impervious surface composition of properties in order to raise capital to deliver better stormwater outcomes. Development of the high-resolution impervious surface dataset as a work product of the Latrobe Prize could accelerate a knowledge-based and egalitarian assessment of impervious surfaces within the US.

Typically, this funding is only a fraction of what is needed. Cities need to find new approaches to meeting this stormwater funding gap. At the same time, it's estimated that 42% of urban land in the U.S. will be redeveloped by 2030. All of this activity has the potential to help address the problem. This is why cities are looking for new ways and means to fund green infrastructure, sometimes on the back of development. One of the ways they are doing this is through Public Private Partnerships (or P3s) to deliver green infrastructure [GI].

P3s, generally speaking, are an agreement for a private entity to deliver stormwater outcomes on both public and private lands and are generally associated with using capital improvement budget dollars, often coming from fees based on stormwater runoff.

What's the benefit? The upsides for a city or agency can be numerous and include:

Cheaper project delivery:

Private companies can deliver stormwater outcomes for close to half of the price compared to cities that undertook projects on their own. The P3 structure enables cities to stretch their capital dollars, delivering more green infrastructure for the dollar.

Reduced delivery risk for the City:
Cities don't need to raise large bonds to finance major capital improvements by engaging private partners for funding and financing.

More Efficient Project Delivery:
Faster project deliveries due to efficiencies with delivering at scale, streamlined approvals and bypassing bureaucratic processes.

Access to Private Land Uses:
Cities can now deploy stormwater green infrastructure work on private lands and not dependent on the public right of way. This is critical because cities and public agencies do not necessarily have access to private land ownership parcels without engaging potentially cumbersome legal mechanisms.

Profits Re-Invested:
When a not-for-profit (501c3) delivery partner is engaged, they transfer any profits from operations back to project related enhancements, like fitting out a basic stormwater detention pond with recreational amenities.

There are existing green infrastructure P3 partnerships already on the ground and working: the Nature Conservancy along with other environmental NGO's are currently working with cities like Detroit, Philadelphia.

Stormwater Policy Trend 2: Stormwater Credit Trading

A second major trend is stormwater credit trading and that Hazel is well positioned to potentially inform and influence.

Essentially credit trading allows the stormwater management requirements of one property (usually mandated under a city ordinance) to be offset by voluntary stormwater management activity in another location, ideally within the same watershed or sewershed leading to a shared downstream water body.

As a case study, imagine the condition of a developer in what is a strong Hazel 3 zone within a high real estate development demand area (i.e. Hazel zone 3 is an area with poor infiltration). Within this zone costs of stormwater management are going to be high requiring implementation of expensive subsurface systems, green roofs, cisterns, or other conveyance infrastructure. However in parts of the city that are in Hazel zone 1, where infiltration is feasible and where there is less development demand, creating the same stormwater outcomes is cheaper. BMPs can be installed on cheaper land.

With credit trading, the developer would transactionally pay for the management of the same or higher volume of stormwater retention generated by their development project within a Hazel zone 1 site(s). This translates into a lower cost for equivalent outcomes.

Establishing Healthy Markets

A healthy market requires both strong demand for credits as well as strong supply—and the supply side can be tricky. It takes significant organization and resources for a supply-side actor to find suitable sites, develop and certify credits, and they need to be reasonably assured that they will be able to sell credits on the back end.

We believe tools like Hazel can help in the early assessment on the demand side, while also identifying suitable sites for credit supply. Using Hazel, credit supply-side actors, like the Nature Conservancy (or other advocates) could quickly identify where the demand is coming from and assess the scale of the demand and find suitable locations to begin planning credit supply projects. Hazel gives us a window into where and how to best implement green infrastructure to take advantage of underlying conditions and maximize private investments.

This is occurring now in places like Washington DC where development in high demand areas of the dense urban core needs to meet the city's combined sewer objectives. Using offsets from a newly-created credit market, development in the dense urban core finances/transfers positive social and environmental outcomes to other parts of the city.

In stormwater credit markets, understanding patterns of supply and demand are essential to success. What we see in efficient markets is a transfer of credits out of markets with high property values and rapid development. At the same time, polices can incentivize and prioritize green infrastructure in places where it can provide the highest benefit. For example, on a high-demand development parcel within a Hazel zone 3 (or equivalent parcel), the developer buys off-site stormwater credits from a voluntary green infrastructure site within an area designated as Hazel zone 1. This transaction is offset from the developer's point-of-view as an opportunity to increase revenues from additional underground parking and rooftop amenities that would have been previously occupied by stormwater infrastructure. Benefits also flow to the voluntary green infrastructure site within the Hazel zone 1: building cost-effective green stormwater infrastructure provides both environmental and social equity co-benefits: local job creation, potential access to open space (assuming the project is located on public land), and reduction of urban heat island effects with increased local biological habit.

Task 8:
Partners + Industry Dissemination and Ongoing Stakeholder Dialog

During stakeholder interviews we recorded potential pathways forward, and obstacles, for future Hazel development and testing. Listed below are the results of these interviews.

Pathways Forward

Validation Requirements:

- Validate the Hazel outputs with input from technical service providers. Specific to public agencies or municipalities, validation might arise from:
a. Establish precedents with previous (and current) users of the tool;

Pilots:

-Use Hazel on a demonstration / pilot project to build consensus and verify output.
-Municipal separate storm sewer system [MS4] permits: use the tool to help categorize private property for assessing MS4 fees, then waiving for green infrastructure improvements (see stormwater policy trends) as an opportunity for demonstrating value/gaining validation. Verify existence of MS4 systems in LA County.
Propose that tool (hydrologic zones/parcel ratings) be tied to MS4 fees; waive the fee for property owners who implement appropriate BMPs. Who would be an appropriate partner to test this with? LA Dept. of Sanitation EWMP for Upper LA River?

Policy Barriers:

-Demonstrate that "better results" are available from Hazel at a lower cost than the methods / tools that are currently in use. Obtaining a "better result" is not a product of the tool's value/worth/integrity—its driven by/derived from policy. Your tool can deliver quantifiable results in terms of water, energy, carbon, possibly dollars and jobs, but it doesn't change that there are rules in place that negate the value of the tool —those rules would have to change before the tool/quantifications have currency/traction. So for example the Burbank Mayor and the LA Mayor would have to say: let's agree that sinking stormwater in the right places is good for both of us (circumvent Pueblo Rights law); only then would BWP or DWP be empowered to act on the advantages your tool offers.

- By far most land is in private hands; your tool addresses that, others do not, including Los Angeles Department of Sanitation EWMP, LA County Flood Control, DWP Stormwater Master Plan; so obviously your tool has advantages, but there's no mandate/incentive for agencies to want them. What are the relevant rules that need to be changed to empower/motivate/activate agencies to address private property?

[Note the NRDC/Heal the Bay/Waterkeeper critique of the EWMP]:
"Lack of specificity of the type, location and timing of BMPs is a common problem throughout the revised WMPs. A lack of specificity results in an uncertain future – it is impossible to understand how permittees will ensure compliance at the required deadlines without a clear plan and milestones."

Task 9:
Stakeholder Outreach, Engagement and Feedback Sessions

Impacts: Measured by Direct Engagement

To date, this Latrobe-funded work has engaged over 1,200 stakeholders from architecture, planning, landscape architecture, public policy and resource management, engineering, technology development and related multi-sectors, and academia.

Architecture:

AIA | California Council Monterey Design Conference, October 2015
Drylands Resilience Initiative: Early-Stage Report from the Latrobe Team w/ Q+A
Presenters: Hadley Arnold, Peter Arnold, Rowan Roderick-Jones, Leigh Christy, Deborah Weintraub.
Approximate number of participants: 120.

AIA National Conference Philadelphia, May 2016
Drylands Resilience Initiative: Progress Report from the Latrobe Team w/ Q+A
Presenters: Hadley Arnold, Peter Arnold, Rowan Roderick-Jones, John Haymaker
Approximate number of participants: 100.

Industry Testing Workshop 1, Perkins+Will Los Angeles, February 24, 2017
"Hazel: Give it a Whirl and Tell US What you Think"
Hands-on testing using case study site.
Presenters: Leigh Christy, Justin Brechtel, John Haymaker
Approximate number of participants: 12

Industry Testing Workshop 2, Los Angeles Cleantech Incubator, March 4, 2017
"Hazel: Give it a Whirl and Tell US What you Think"
Hands-on testing using case study sites.
Presenters: Peter Arnold, Justin Brechtel, John Haymaker
Approximate number of participants: 22

AIA National Conference, Orlando, April 2018
"Latrobe Research Prize Results: Designing for Climate Adaptation in Drylands" w/ Q+A
Presenters: Hadley Arnold, Peter Arnold, Leigh Christy, Justin Brechtel, Rowan Roderick-Jones
Approximate number of participants: 100

Planning:

American Planning Association National Conference, Oakland, October 2015
The Los Angeles River: Recalibrating the Role of Water, Infrastructure and Place
Moderator: Mary Creasman, California Director of Government Affairs, The Trust for Public Land
Speakers: Mark Hanna, Principal Water Resources Engineer, Geosyntec; Peter Arnold, Co-Director, Arid Lands Institute; Benjamin Feldmann, ASLA, LEED AP, Senior Associate, Mia Lehrer + Associates
Approximate number of participants: 80.

City of Los Angeles Mayor's Office, Great Streets Initiative: Connect the Dots, 2015-2016
Led by one of Hazel's first trial users, recent ALI MSArch grad Aja Bulla-Richards, Connect the Dots design workshops introduced Hazel data and methods to a broad public. Piloted in Pacoima (July 2015), Connect the Dots secured Great Streets funding in July 2015 and launched in Van Nuys, February 2016. Connect the Dots collaborated with members of the Mayor's office, Council District 6, LA County Metropolitan Transit Authority, neighborhood schools, Van Nuys Neighborhood Council, and environmental justice non-profits to visualize Van Nuys Boulevard as a Great Street incorporating multi-benefit stormwater capture opportunities. More at aridlands.org.
Approximate number of participants: 250

USGBC Municipal Green Build Expo, Los Angeles, May 2016
Drylands Resilience Initiative: Report from the Latrobe Team w/ Q+A
Presenters: Hadley Arnold, Rowan Roderick-Jones, Leigh Christy
Approximate number of participants: 40.

Landscape Architecture:

American Society of Landscape Architects National Convention, Chicago, November 2015
Where Desert Meets the Sea: Dry Cities and Climate Change
Moderator: Margot Jacobs, ASLA, ASLA, LEED AP, Senior Associate, Mia Lehrer + Associates
Presenters: Elizabeth Mossop, ASLA and Hadley Arnold, co-director, ALI
Approximate number of participants: 80.

Landscape as Necessity Conference, USC School of Architecture, Los Angeles, September 2016
"New Tools for Climate Adaptation in Drylands"
Presenter: Hadley Arnold
Approximate number of participants: 120

Public Policy and Resource Management:

CA State Senator Robert Herzberg and District 18 staff, Van Nuys CA, May 2016
Hazel: New Tools for Climate Adaptation
In-depth presentation and critical discussion w/ Sen. Herzberg, chair, Natural Resources Committee, CA State Senate.
Presenters: Peter Arnold, Hadley Arnold
Approximate number of participants: 18

Reimagining the Cadillac Desert, Autry Museum, Los Angeles, September 2016
Water Rights, Water Governance Symposium hosted by Best Best & Krieger Attorneys at Law
"Meet Hazel: New Tools for Climate Adaptation in Drylands."
Presenter: Hadley Arnold
Approximate number of participants: 60

Digital Tools Forum, City of LA Mayor's Office, September 2016
"Hazel: New Tool for Climate Adaptation in Drylands"
Presenter: Peter Arnold
Approximate number of participants: 60

Watershed Based Planning Dialog with City of Austin, TX, October 2016
Participants: City of Austin Watershed Planning offices, Austin water agencies, Austin water conservation programs, City of Austin Mayor's 0ffice
Presenters: Leigh Christy, Rowan Roderick Jones, Hadley Arnold
Approximate number of participants: 20

Coro Foundation Water Forum, LACI, November 2016
"Hazel: New Tool for Climate Adaptation in Drylands"
Presenter: Peter Arnold
Approximate number of participants: 80

Miscellaneous meetings with Public Works Commissioners and Agency Managers, City of Los Angeles, 2016-2017.
Approximate number of participants: 24

Engineering/Tech/Multi-Sector

SxSW Eco Conference, Austin TX, October 2016
Drylands Resilience Initiative: Report from the Latrobe Team w/ Q+A
Presenters: Hadley Arnold, Leigh Christy, Rowan Roderick-Jones, Deborah Weintraub
Approximate number of participants: 40

LA Cleantech Incubator Water Cluster, LACI, October 2016
"Hazel: New Tool for Climate Adaptation in Drylands"
Presenter: Peter Arnold
Approximate number of participants: 40

Multiple small-group presentations @ LA Cleantech Incubator, 2016-2017.

Academia

University of New Mexico School of Architecture, Albuquerque NM, January 2016
"Divining LA_New Tools for Design in Drylands."
Presenters: Hadley Arnold, Peter Arnold
Approximate number of participants: 80.

Colorado College, State of the Rockies Lecture Series, Colorado Springs CO, February 2016
"Divining LA_New Tools for Design in Drylands."
Presenters: Hadley Arnold, Peter Arnold
Approximate number of participants: 80.

Fluvial Metropolis Workshop, Princeton University School of Architecture, Princeton NJ April 2017
"Divining LA_New Tools for Design in Drylands."
Presenters: Hadley Arnold
Approximate number of participants: 16.

Mass Communications

"Could LA Design Its Way to Water Independence?" by Sarah Tory. High Country News. November 30, 2015.
http://www.hcn.org/issues/47.20/the-tenuous-revival-of-mono- lake/could-los-angeles-design-its-way-to-water-independence

"Water Resilient Cities: How is Business Building Them?" Moderated by Tess Riley. The Guardian. October 26, 2015.
http://www.theguardian.com/sustainable- business/live/2015/oct/20/sponge-cities-what-business-doing-to-build-water-resilient- cities-of-the-future

"Here's a highly rational, totally plausible fix for drought in cities." By Alissa Walker. Gizmodo. June 25, 2015.
http://gizmodo.com/heres-a-highly-rational-totally-plausible-fix- for-drou-1713918502

"Two Experts Are Here to Answer Your Questions About the Drought." Gizmodo. June 25, 2015.
http://gizmodo.com/ask-two-water-experts-your-questions-about-the-drought-1713934465

Divining LA and Hazel video in, "For the People: Design for A Better America," Cooper Hewitt Smithsonian Design Museum, New York, September 2016-February 2017.

<u>Assumptions Questioned and Impacts Projected</u>

We entered the Latrobe Research process with several assumptions underlying our work: that Hazel was principally for urban applications; that Hazel was principally driven by water supply; and that Hazel was for climate adaptation in drylands.

Feedback from our extensive interaction with potential users in public settings around the country lead us to question or extend some of those assumptions. Hazel's applications in agricultural settings, for example, have been noted by groundwater managers and regulators in the Central Valley and Northern California. While Hazel was designed to address water supply, its application to water quality management in the urban northeast---Philadelphia, Washington, and the Tri-State are have been noted. We have been approached about Hazel's potential value not only securing water supply in drylands, but mitigating flood risk in humid lands, especially along the Gulf Coast and the southeastern US. And we have been approached about Hazel's ability to facilitate thoughtful dialog around precious resources in highly contested landscapes from Kabul to the Jordan Valley.

These forms of feedback challenge and inspire us to continue questioning and developing Hazel. As we do, we stand by the impacts we projected at the outset of the Latrobe process. As we move forward with Hazel and bring it to wide use, we are confident of its impacts:

On Tool Design

Hazel operates as a high-level computational engine, the first of its kind to integrate overland surface flow, groundwater flow, and the design of the built environment into a dissemination tool, communicating in real time the implications of design choices that couple human and natural systems. Hazel integrates water supply with water quality considerations, and correlates performance data including embodied energy, carbon emissions, and economic implications to evaluate design decisions. Hazel will be designed, tested, and implemented in Los Angeles; however the technology is adaptable to datasets from other locations, exportable to arid regions worldwide.

On Design Practice

Hazel irrevocably benchmarks local water harvesting as a baseline urban design constraint, comparable to density, transit, or seismic activity as inseparable from intelligent place- and form-making in 21st century Los Angeles and arid and semi-arid environments like it. Design education, professional licensure, and informed, competent practice will not be possible without it. With the emergence of a water-conversant design profession, new forms of water-sensitive building systems, urban form, and policy recommendations will also emerge. Water will shape design thinking; design will shape water thinking.

On Research Practice

The Drylands Resilience Initiative [DRI] is a model for future research-based practices:
DRI coordinates, integrates, applies, tests, and disseminates new and ongoing research between academia, public agencies, private technical service providers and non-governmental organizations. If funded, this project will be the first Latrobe Prize awardee to involve a committed public sector partner as an integral team member.

On Disciplinarily

Future practices will fuse science and policy with design thinking to address the complex challenges of a changing climate for practical public benefit—specifically, to realize resilient, localized, low-carbon water supply systems for urban drylands. Complex urban problems require dissolution of traditional disciplinary silos between the physical sciences (geography, hydrology, geology, ecology), the social sciences (economics, public policy) with the allied design and engineering professions.

On Systems Thinking

Hazel challenges design professionals to engage multiple scales and time horizons.
Interconnected urban processes occur at multiple scales and across deep time horizons and require tools and methods not familiar (yet) to the design professions.

On Public Policy

Hazel, and the innovations it is designed to foster, will result in:

- Recommended overhauls to building code, to make room for new approaches to building-integrated water–harvesting systems;

- Changes to zoning, as hydrologic overlay zones (capture, infiltrate, treat, store, distribute) assign appropriate functions to each neighborhood of the city;

- New forms of watershed governance and markets, across political boundaries.

- New hyper-local governance models in networked neighborhoods and small-scale water cooperatives;

On Public Space

Improved data-driven decision-making will not only accelerate climate-mitigation and adaptation—increasing availability to local water supply and lower GhG emissions; it will also drive greater levels of architectural and urban invention—re-investing forms and surfaces of public architectures in drylands with a kind of chthonic—deeply rooted—purpose. We see Hazel precipitating design innovation at multiple levels—urbanist and architectural—helping to shape a public realm animated by building materials, systems, and forms drawn from the diverse biophysical, climatic, and cultural character of drylands. Civic infrastructures and public architectures that transparently shape a water-smart public realm also shape the true basis of drylands sustainability: a water-conversant, or water-literate, citizenry.

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