

RECYCLED MATERIAL WEB MAP:
CONNECTING CONSUMERS
AND PRODUCERS

by

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ABSTRACT

An online Geographic Information System (GIS) web application that connects producers and consumers of recyclable material was developed to assist engineers and contractors in the beneficial reuse of recycled materials in transportation projects. The Recycled Material Web Map is comprised of four core layers: producers, stockpiles, specifications, and case studies. Producers of recycled material can locate their facility and enter contact information. The stockpile layer, connected to the producer layer, allows facility managers to add or update information about their recycled material stockpiles including material type(s), application(s), availability, and cost. Multiple stockpiles can be associated with each producer. The specification layer includes both Department of Transportation (DOT) specifications and environmental regulations pertaining to the beneficial reuse of nonhazardous recycled material based on specific location, material type, and application. The case study layer locates transportation projects that successfully utilized recycled materials and includes information regarding the material type, application, volume data, and any additional documentation.

As potential consumers of recycled material, engineers and contractors can pinpoint the location of a construction project, search for sources and quantities of recycled material that meet project specifications, and contact material producers. The web map utilizes search capabilities to locate nearby stockpiles to minimize transportation costs that typically dictate the use of large volumes of materials. The Recycled Material Web Map provides key information that engineers and contractors need to successfully utilize recycled materials, thereby preserving limited natural

resources and benefiting the project and society as a whole. The web map is available at <http://rmwm.caps.ua.edu>.

DEDICATION

Not only does it take a village to raise a child, but it also takes a village to complete a research project, write a thesis, and earn a master's degree. There have been many people who have guided me, provided opportunities to me, and encouraged me to walk through open doors throughout my college career. This manuscript is dedicated to each and every one of those people.

In addition, I would like to thank my family for investing in my education, pushing me to be the best I could be, and supporting my dreams. Many of the opportunities I have enjoyed would not have been possible without Dr. Andrew Graettinger and Dr. Randy Smith, and I would especially like to thank them for their advice, encouragement, and mentorship. Finally, I would like to thank my friends and the Civil Engineering GIS Research Group for their inspiration, contributions, and unwavering friendship over the years.

LIST OF ABBREVIATIONS

| | |
|--------|--|
| AASHTO | American Association of State Highway and Transportation Officials |
| ADEM | Alabama Department of Environmental Management |
| AFS | American Foundry Society |
| CAPS | Center for Advanced Public Safety |
| DOT | Department of Transportation |
| EPA | Environmental Protection Agency |
| ESRI | Environmental Systems Research Institute |
| FHWA | Federal Highway Administration |
| GIS | Geographic Information System |
| IDE | Integrated Development Environment |
| PCC | Portland Cement Concrete |
| QA/QC | Quality Assurance/Quality Control |
| RAP | Recycled Asphalt Pavement |
| RAS | Recycled Asphalt Shingles |
| RCA | Recycled Concrete Aggregate |
| RMRC | Recycled Material Resource Center |
| SFS | Standard Folder Structure |
| Spyder | Scientific PYthon Development EnviRonment |
| TxDOT | Texas Department of Transportation |

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CONTENTS

| | |
|--|----|
| ABSTRACT..... | ii |
| DEDICATION..... | iv |
| LIST OF ABBREVIATIONS..... | v |
| ACKNOWLEDGEMENTS..... | vi |
| LIST OF FIGURES | ix |
| CHAPTER 1 INTRODUCTION | 1 |
| 1.1 Introduction..... | 1 |
| 1.2 Thesis Organization | 1 |
| CHAPTER 2 BACKGROUND AND LITERATURE REVIEW | 3 |
| 2.1 Introduction..... | 3 |
| 2.2 Department of Transportation Use of Recycled Material..... | 4 |
| 2.3 Previous and/or Existing Material Exchanges | 7 |
| CHAPTER 3 METHODOLOGY | 11 |
| 3.1 Overview..... | 11 |
| 3.1.1 Producer and Stockpile Layers | 12 |
| 3.1.2 Specifications and Regulations Layer..... | 12 |
| 3.1.3 Case Study Layer | 13 |
| 3.2 Recycled Material Web Map Database..... | 13 |
| 3.3 Recycled Material Web Map Functionality | 14 |
| 3.3.1 General User Level | 16 |
| 3.3.2 Producer User Level | 20 |

| | |
|--|----|
| 3.3.3 Advanced User Level: Researcher/Agency | 22 |
| 3.4 Quality Assurance and Quality Control | 24 |
| 3.5 Desktop Routing Tool..... | 25 |
| 3.5.1 Desktop Routing Tool Methodology | 25 |
| 3.5.2 Desktop Routing Tool Results | 29 |
| 3.5.3 Desktop Routing Tool Future Work | 32 |
| 3.6 Conclusion | 33 |
| CHAPTER 4 RESULTS | 34 |
| 4.1 Current Data..... | 34 |
| 4.2 Current Status..... | 35 |
| 4.3 Benefits | 36 |
| CHAPTER 5 CONCLUSION AND FUTURE WORK | 37 |
| 5.1 Conclusion | 37 |
| 5.2 Future Work | 37 |
| REFERENCES | 39 |
| APPENDIX A RECYCLED MATERIAL WEB MAP USER GUIDE..... | 41 |
| APPENDIX B DESKTOP ROUTING TOOL | 62 |
| Installation Instructions..... | 64 |
| User Guide | 69 |
| Python Code..... | 76 |

LIST OF FIGURES

| | |
|---|----|
| Figure 2.1. North Carolina Waste Trader website material availability results (North Carolina Department of Environment and Natural Resources, 2015). | 9 |
| Figure 3.1. Recycled Material Web Map table schema with primary keys underlined, required attributes preceded by a solid dot, and table relationships shown as arrows. | 14 |
| Figure 3.2. Recycled Material Web Map default map view showing the map area with producers, stockpiles, and case studies on an ESRI basemap (ESRI, 2015), the results grid at the bottom of the screen, and a sidebar with multiple panels for searching the site. | 16 |
| Figure 3.3. (a) Consumer Search panel includes options to search by state and/or material type or search by radius. (b) Radius search selects all producers and stockpiles within a specified radius (ESRI, 2015). | 17 |
| Figure 3.4. The specifications and regulations tab includes DOT specifications, environmental regulations, and additional information pertaining to the beneficial use of recycled material. | 19 |
| Figure 3.5. Case study synopsis window displays key information including project name, materials used, description, and link(s) to project documentation (ESRI, 2015). | 20 |
| Figure 3.6. Example facility and stockpile (circled in this figure) that are added and updated on the Producers and Stockpiles panel. The stockpile details are listed beneath the Producer contact information (ESRI, 2015). | 21 |
| Figure 3.7. (a) Example specifications listed by agency, group, and section in the Recycled Material Web Map Reg-Spec Editor. (b) Reg-Spec Editor dialog box for entering and updating specifications, regulations, and additional information. | 23 |
| Figure 3.8. Case study data entry form to add and update case study information (ESRI, 2015). | 24 |
| Figure 3.9. Example step-by-step route directions printed in Spyder IDE console. | 30 |

Figure 3.10. Example nearest_5_piles table displaying the five closest stockpiles to the project location.....30

Figure 3.11. Example ArcMap Document generated from RMWM desktop routing tool.....31

Figure 3.12. Example PDF map generated from the RMWM desktop routing tool.....32

Figure 4.1. States that have regulatory information in the Recycled Material Web Map.35

CHAPTER 1

INTRODUCTION

1.1 Introduction

Over a half of a billion tons of recyclable material including construction and demolition debris, foundry sand, coal combustion products, and slags are produced each year in the United States (United States Environmental Protection Agency [U.S. EPA], 2009). Nonhazardous waste products generated from manufacturing, industry, and electric utilities have the potential to be reused for a variety of transportation construction applications. Currently, the widespread use of these potentially recyclable materials is deterred by a lack of information. To feel comfortable, an engineer or contractor needs to: recognize the beneficial use of a material, understand the specifications and regulations that apply to a material, be able to locate an available source of recyclable material, and see examples of this material used in other projects. Keeping these aims in mind, the Recycled Material Web Map is an all-in-one tool that connects consumers to producers by providing accessible, location-based recycled material information.

1.2 Thesis Organization

This thesis is divided into five chapters. Chapter 2, Background and Literature Review, presents an overview of how several Departments of Transportation (DOTs) locate and use recycled material and discusses some of the current barriers preventing increased beneficial reuse. The literature review summarizes existing research related to previous material exchanges, web application routing, and automated quality controls for websites. Chapter 3,

Methodology, describes the development and functionality of the Recycled Material Web Map and the desktop routing tool. Chapter 4, Results, presents the current status of the Recycled Material Web Map and ongoing data entry efforts. Chapter 5, Conclusion and Future Work, discusses the results of this research in further detail and suggests potential future work related to the continued growth and development of the Recycled Material Web Map. The Recycled Material Web Map User Guide is included in Appendix A. Supplementary information about the desktop routing tool including the user guide, Python code, and installation instructions are contained in Appendix B.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

As the world increasingly consumes limited resources and produces waste, recycling and reusing material becomes more important. There is an increasing trend of recycling in the United States as demonstrated by an U.S. Environmental Protection Agency (EPA) fact sheet that reports a twenty-eight percent increase in municipal solid waste recycling rates over the last fifty years (U.S. EPA, 2015). Society has the enthusiasm to recycle but not always the means to do so, especially within the industrial sector. Businesses must consider the economic risks and rewards of recycling byproducts. In some cases, landfill tipping fees are cheaper than the cost of recycling material which causes a large amount of potentially useful material to be disposed of in landfills. For example, the City of Tuscaloosa Environmental Services Department once maintained a glass recycling program, but most of the glass collected ended up sent to the landfill because of the large distance to the closest traditional glass recycling processor and the low market value of the recycled product. However, the City of Tuscaloosa received a grant in 2014 from the Alabama Department of Environmental Management (ADEM) and purchased a glass pulverizer allowing the collected glass to be used locally to replace sand and gravel in roadbed projects, pipe insulation, and several other applications (Morton, 2015). Industry continues to focus on sustainably managing materials and looking for opportunities to attain economic growth while minimizing environmental impact.

Nearly every major industrial process, spanning from mining and energy generation to agriculture and textile manufacturing, creates byproducts that can be reused in a variety of applications. Application for the reuse of the byproducts include aggregate in pavement, structural fill, road embankments, and manufactured consumer products. Examples of some of the most commonly used nonhazardous industrial byproducts in construction applications include recycled concrete aggregate (RCA), recycled asphalt pavement (RAP), recycled asphalt shingles (RAS), coal fly ash, blast furnace slag, and rubber (Bloom et al, 2016). There have been many efforts to characterize the engineering properties of these materials, test the materials in varied applications, raise awareness about the potential usefulness of these materials, and market the byproducts as commodities. Studies have found that the engineering properties of these materials are the same, or in some cases better, than the virgin materials they replace. Some of the major benefits of using recycled materials include reducing the demand for limited resources, conserving energy and decreasing greenhouse gas emissions, and saving money on disposal costs for the generator and material costs for the consumer (U.S. EPA, 2016). Therefore, there is a growing market to locate and use industrial byproducts in both the public and private sectors.

2.2 Department of Transportation Use of Recycled Material

State DOTs are some of the largest consumers and producers of recycled materials across the country. There are over 4 million miles of public roadways in the United States. As of 2013, 32% of the roadway network was considered to be in poor or mediocre condition and in need of rehabilitation (Herrmann, 2013). Roadway rehabilitation generates reusable materials such as RAP and RCA that can be reused in-place or for another local applications. In addition, roadway and bridge construction provides an opportunity to use many other industrial byproducts for

applications including, but not limited to: asphalt concrete pavement, Portland cement concrete (PCC) pavement, granular base, embankment, structural fill, stabilized base, flowable fill, and compost (Recycled Material Resource Center, 2016). A Recycled Material Resource Center (RMRC) study surveyed six state DOTs (Georgia, Illinois, Minnesota, Pennsylvania, Virginia, and Wisconsin) to quantify the amount of recycled materials that are used in highway construction in order to conduct a life cycle assessment for each state. Illinois was the only state surveyed that requires the DOT to report the quantity of recycled material used. Tracking recycled material quantities is challenging and often not effective for most DOTs. However, as-let material quantities for projects were available and used to back-calculate the quantities of recycled materials used in hot mix asphalt, concrete mixes, and base course layers for a one year period. The six states cumulatively used 7.7 million tons of recycled material in highway projects in 2013. RAP, RCA, and fly ash were used most extensively across the states, while Illinois also tracked steel slag, by-product lime, glass beads, microsilica, dowel bars, rebar, and welded wire reinforcement. The study found the average environmental impacts savings of using recycled material in highway construction instead of virgin resources to be between 80-97% (Bloom et al, 2016). As DOTs continue to increase the use of recycled material for construction projects, a tool to track source material and quantities for each project would be beneficial and useful for many applications such as life cycle assessment.

There are numerous laws and guidelines that govern the use of recycled materials in transportation projects. In addition to federal specifications and regulations, each state maintains DOT specifications and environmental regulations that govern the use of recycled material used in construction projects. There are several websites that post links to specifications or regulations for the United States. For example, the EPA provides an online tool that identifies

the rules and programs regarding the beneficial use of recycled materials for each state called the Beneficial Reuse State Resource Locator. The locator provides information regarding state policies, applicable agencies/divisions, regulations, beneficial reuse definitions, and approved materials, but information concerning construction specifications is not included in this portal (National Center for Manufacturing Sciences, 2016). The National Highway Specification Website is a clearinghouse and electronic library where users can search and download current specifications, construction manuals, and drawings, but does not have information regarding environmental regulations. However, links to specifications are often updated or removed by the agencies, which causes broken links or outdated information to occur (Federal Highway Administration, 2009). Currently, there is not a single website that is a source for both regulations and specifications nationwide.

Interestingly, science changes at state lines. State lines are arbitrary to the engineering properties of the recycled material; and the geology of the earth, yet they limit the beneficial use of industrial byproducts in some cases. Using Class C fly ash for base course material may be legal and common practice in one state; but ten feet across the state line the recycled material cannot be used on the same project, regardless of the similarities in geology, weather, topography, etc. Ideally, engineers would research surrounding states possibilities, and communicate with lawmakers to work towards removing excessive barriers to the use of recycled material.

In addition to divergent specifications and regulations, there are several other limitations that inhibit the use of recycled material in construction projects. Even though recycled materials are increasingly being used in transportation construction, many engineers do not feel completely comfortable incorporating the secondary materials into their designs. In order to overcome this

lack of knowledge, there is a need for easy access to case studies, or examples of where recycled material has been successfully utilized in construction projects, and the applicable specifications and regulations. Locating available material stockpiles is also a challenge when designing with secondary materials. In many cases, stockpiles of potentially useful materials are disposed of in a landfill instead of being beneficially used due to either proximity issues (shipping costs typically dictate the use of recycled material) or lack of advertising (engineers are not aware the material is available). Finally, some state agencies track yearly quantities for the recycled materials used most often, but the material quantities are not tracked on a project by project basis in the same way conventional materials are tracked. Therefore, it is a challenge to clearly convey the economic and environmental benefits of substituting recycled materials for virgin materials.

2.3 Previous and/or Existing Material Exchanges

Extensive research has been conducted on the engineering uses and applications of recycled material; however, there are limited tools available to map the locations of the material generators and stockpiles. The Texas Department of Transportation (TxDOT) Reclaimed Materials Supplier Map provides an example of a GIS-based online map that spatially displays the locations of recycled material generators and processors. Users can add and edit recycled material facilities. Facilities can be identified by searching for districts, counties, and/or material type. Each material type is associated with a unique symbol, and the map can be thematically mapped by toggling on/off material type(s) in the legend. In addition, zoom options including zoom to county, clustering, and circle measure are included. The circle measure tool allows the user to search for facilities in a specified radius of a chosen location (Texas Department of

Transportation, 2014). However, this application does not include information about the generator quantities, cost, or material applications. As of 2015, the tool is no longer available online. In 2003, TxDOT conducted a separate study to create an information system prototype to track the availability, location, and material specifications of nonhazardous recyclable materials for transportation construction projects. While the prototype website successfully tracked various recycled materials, the website is no longer active. Researchers concluded that the system itself worked well and the technology was useful, but full-implementation of the system was not feasible because of competition, confidentiality, and the immaturity of recycling infrastructure at the time (Landphair et al, 2003).

The majority of the material exchange online applications reviewed, at the national, regional, and state level, provide a listing of recycled material advertisements without a location based map of the suppliers. There are several of these listing-type websites that operate on a national scale such as the American Foundry Society (AFS). The AFS website provides a directory system of more than 2,500 metal casters, which can be searched by alloy, process, casting weight, country, and/or state (American Foundry Society, 2015). The directory does not include a location map, quantities available, or cost. Additionally, several of the Environmental Protection Agency (EPA) regions have initiated waste exchange listing websites as well. The Resource Exchange Network for Eliminating Waste tool provides EPA Region 6 (Arkansas, Louisiana, New Mexico, Oklahoma, Louisiana and Texas) with a listing-type material exchange website. The listings are sorted by material type and include contact information and a brief description of the material. Location (city, state), quantity, and cost information is included in the descriptions, but a location map is not provided (Zero Waste Network, 2015). A large amount of listing-type material exchange websites exist on the state or local level. Websites

were reviewed for the following states: Pennsylvania, Iowa, Maine, Minnesota, and North Carolina. Some states had more advanced and inclusive websites than others, but none of them featured mapping capabilities (iWasteNot Systems Inc., 2015; Pennsylvania Department of Transportation, 2015; Iowa Department of Natural Resources, 2015; M2X, 2000; North Carolina Department of Environment and Natural Resources, 2015). Figure 2.1 illustrates the North Carolina Waste Trader website material availability page, exemplifying the standard listing-type web application used across the nation as opposed to the inclusion of a web-based location map (North Carolina Department of Environment and Natural Resources, 2015).

N O R T H C A R O L I N A
WasteTrader

[Materials Available](#) [Materials Wanted](#) [Need Help?](#)

List of waste materials available:

Date listed ▼ Descending ▼ Sort **SEARCH LISTINGS**
 Search keyword(s) Go

| Material Name | Amount on Hand | Frequency Available | Price (\$) | City | State | Date Listed |
|-----------------------------|-------------------|----------------------|--------------------------|------------|-------|-------------|
| Lumber | 200 board feet | one time, continuous | 2 dollars per board foot | Waxhaw | NC | 11/04/15 |
| 3 Ring Binders | 300 binders | annually | \$0 | Durham | NC | 11/02/15 |
| Meltblown Nonwoven Textiles | 60,000 lbs. | Monthly | Market pricing | High Point | NC | 10/29/15 |
| Silica Matting Agent | 540 lbs | one time | \$1 per pound | Lillington | nc | 10/16/15 |
| Sand | about 0.25 gallon | one time | free upon pick up | Durham | NC | 09/14/15 |
| Oak Mats Rough Ground | 4000 cu yds | one time | | Jarvisburg | NC | 06/23/15 |
| sheetrock | 20+ tons | monthly | FREE | Lillington | NC | 04/28/15 |
| PVC Pipe | 3000 pounds | quarterly | .05 | Charlotte | NC | 04/01/15 |

Figure 2.1. North Carolina Waste Trader website material availability results (North Carolina Department of Environment and Natural Resources, 2015).

Many studies have been conducted on recycled material properties and their use in specific construction applications. In addition, there are numerous material exchange websites that provide a way for facilities and companies to post available and/or wanted material type(s), quantities, cost, and material characteristics. However, there is a gap in available technology that connects the producers to the consumers of recycled materials on a location basis, in addition to the parameters listed above. The Recycled Material Web Map will close this gap by creating an online GIS-based tool that includes location and availability of recycled material sources, past projects that successfully used recycled material, and specifications and regulations that pertain to the use of recycled material in construction projects.

CHAPTER 3

METHODOLOGY

3.1 Overview

The primary objective of this research project is to promote the use of recycled material through the creation of a single-source web application. The Recycled Material Web Map provides potential consumers of recycled material an online location-based information system that displays material stockpiles, sources, applicable specifications and regulations by state, and case studies of past design and construction projects that utilized recycled material.

The Recycled Material Web Map was developed by the Center for Advanced Public Safety (CAPS) at The University of Alabama. CAPS is a non-profit research and development center that uses cutting-edge information technology to solve many data and information problems. Currently, CAPS has a professional staff of over 135 employees comprised of developers, faculty, and staff who have a wide range of technical expertise including Geographic Information Systems.

A typical software development cycle was performed to design the Recycled Material Web Map. As part of the development, a thorough literature review of existing recycled material exchange websites was performed, meetings with the project advisory group were held, and extensive prototyping and testing of site components was carried out. Based on the findings of the literature review and correspondence with the advisory group, four map layers were identified as key components of the Recycled Material Web Map. These layers are: producers, stockpiles, specifications/regulations, and case studies. With these four core layers and

associated information, the Recycled Material Web Map provides valuable information in a user-friendly online tool to promote recycled material use in transportation projects.

3.1.1 Producer and Stockpile Layers

The four layers of the Recycled Material Web Map each provide spatially related information to aid in the use of recycled material in construction projects. The producer layer includes contact information for facilities that generate recyclable material. Facility managers can update material type, application, and quantity information in the stockpile layer. Every stockpile is associated with a producer, but producers are not required to have active stockpiles. Both producers and stockpiles can be designated historic if the material is no longer available or after a period of inactivity. To keep the information current on the website, producers can supply a web service that automatically updates the stockpile quantities. If a service is not available, the producer can be automatically contacted by email to confirm that their stockpile quantities are up to date. If the stockpile information is out-of-date (older than nine months), the stockpile(s) will time out and become historic to ensure quality map data.

3.1.2 Specifications and Regulations Layer

Department of Transportation specifications and environmental regulations that pertain to the beneficial reuse of industrial byproducts or other recyclable materials were initially collected for six states (Wisconsin, Virginia, Pennsylvania, Minnesota, Illinois, and Georgia) and three federal agencies (American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), and Environmental Protection Agency (EPA)) to populate the regulation and specification layer. Additional specifications and

regulations have been collected for a total of seventeen states since the initial phase of the project. These states include: Alabama, California, Colorado, Florida, Georgia, Idaho, Illinois, Michigan, Minnesota, Nevada, North Carolina, Oregon, Pennsylvania, Texas, Virginia, Washington, and Wisconsin. Hyperlinks to the specific sections of these regulatory documents at the state and federal agencies are available on the web map and are searchable by state, material, and application.

3.1.3 *Case Study Layer*

The case study layer locates construction projects that successfully utilized recycled material. In addition to the material type(s) and application(s) used in the project, the additional information stored in the case study layer include a synopsis of the project, pictures, and any other project documentation such as final reports or presentations.

3.2 Recycled Material Web Map Database

The Recycled Material Web Map utilizes a relational database to store information that can be edited and updated online by users with appropriate authorization. The table schema for the website is shown in Figure 3.1, where tables are depicted as boxes that contain attributes and relationships between the parameters of the core layers of the web map are shown as arrows. The producer contact information is linked to both stockpiles and case studies. Stockpiles are associated with both producers and material type. Specifications and regulations contain both material and application type information. Material type(s) are recorded for each case study, and the producer who supplied the recycled material can optionally be connected to the case study.

There are several additional linking tables used to normalize the database that are not included in the figure below.

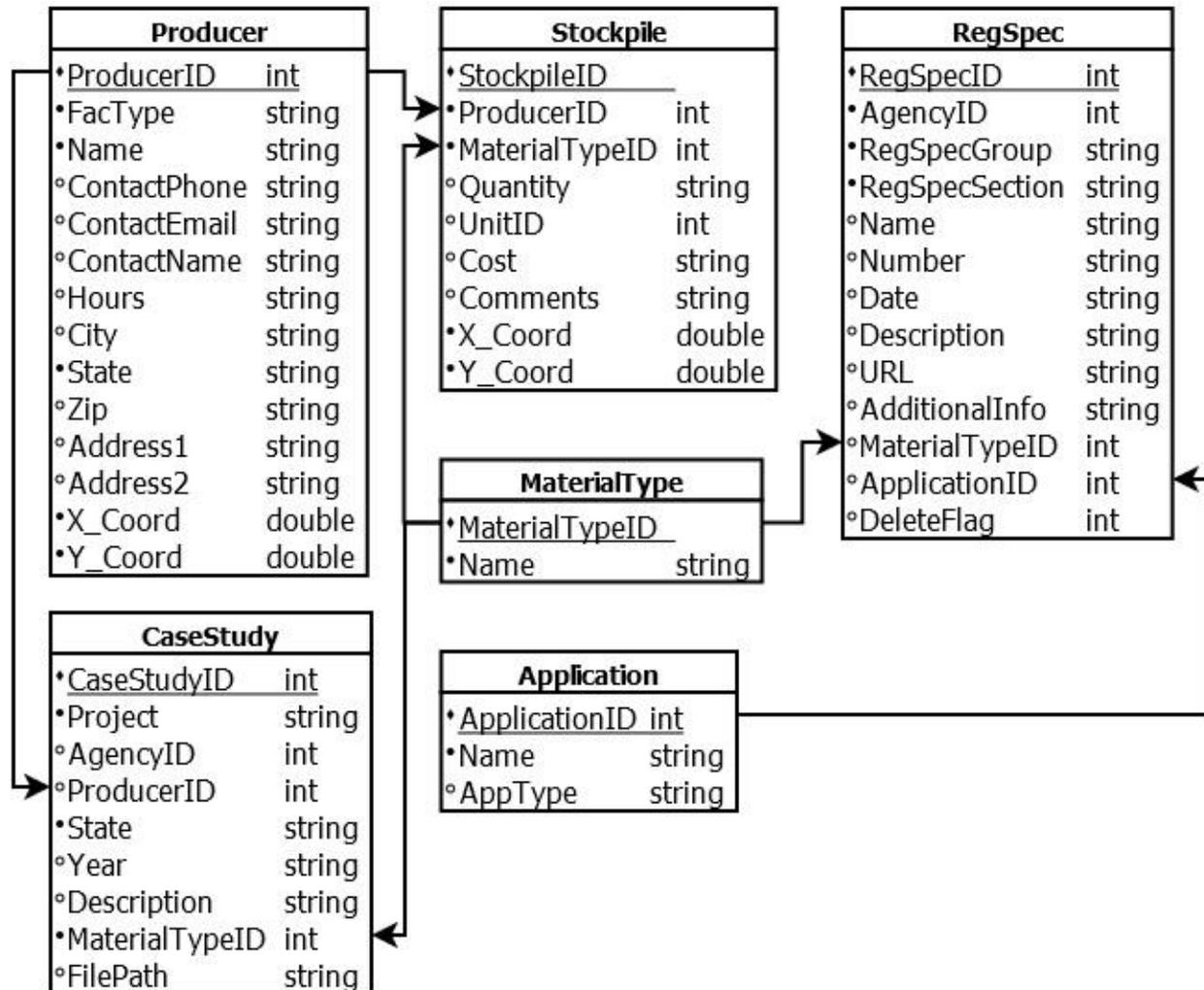


Figure 3.1. Recycled Material Web Map table schema with primary keys underlined, required attributes preceded by a solid dot, and table relationships shown as arrows.

3.3 Recycled Material Web Map Functionality

The Recycled Material Web Map was designed as an interactive online tool and supporting website. The website evolves as new producers, stockpiles, and case studies are added. Figure 3.2 displays the default map view of the website underlain by an Environmental Systems Research Institute (ESRI) basemap that toggles between street view imagery and aerial

imagery (Environmental Systems Resource Institute [ESRI], 2015). Facilities are depicted with factory symbols, stockpiles are shown as triangles, and case studies are represented as rectangles. Users can zoom in and out of the map using the plus or minus buttons located on the top left corner of the map view or by selecting a state from the drop down menu on the search panel. When a state is selected, the map zooms in to the state level, and users can zoom in further to view a project site by using the plus button or scroll in using the wheel of the mouse. Across the top of the default screen are tabs that include: Map, which is the default view; Specifications/Regulations, which displays state and federal information; and Reg-Spec Editor, which allows advanced users to enter and maintain specifications and regulations. The side bar to the left of the map screen includes several panels: Consumer Search, Producers and Stockpiles, Case Studies, and Help. The Consumer Search panel allows users to search for stockpiles, producers, specifications and regulations, and case studies. With appropriate login credentials, facility contact information and stockpile data can be entered on the Producers and Stockpiles panel. Case study information and associated project documents can be uploaded using the Case Studies panel. The Help panel includes a user guide and several video tutorials of the major components of the website. The result grid at the bottom of the default map screen displays producers, stockpiles, and case studies that are selected based on the search criteria applied in the Consumer Search panel. The map features a user-friendly interface and is accessible on mobile devices.

There are three user levels associated with the Recycled Materials Web Map: general user, producers or suppliers of recycled material, and advanced users. General users can search for local recycled materials, specifications, and case studies that utilized recycled material in construction projects. Producers can promote material by entering, updating, and maintaining

material source information. Additionally, advanced users such as researchers and DOT agencies, can add DOT specifications, environmental regulations, and case studies. The Recycled Material Web Map application was designed to provide specific functionality for each of these three user levels.

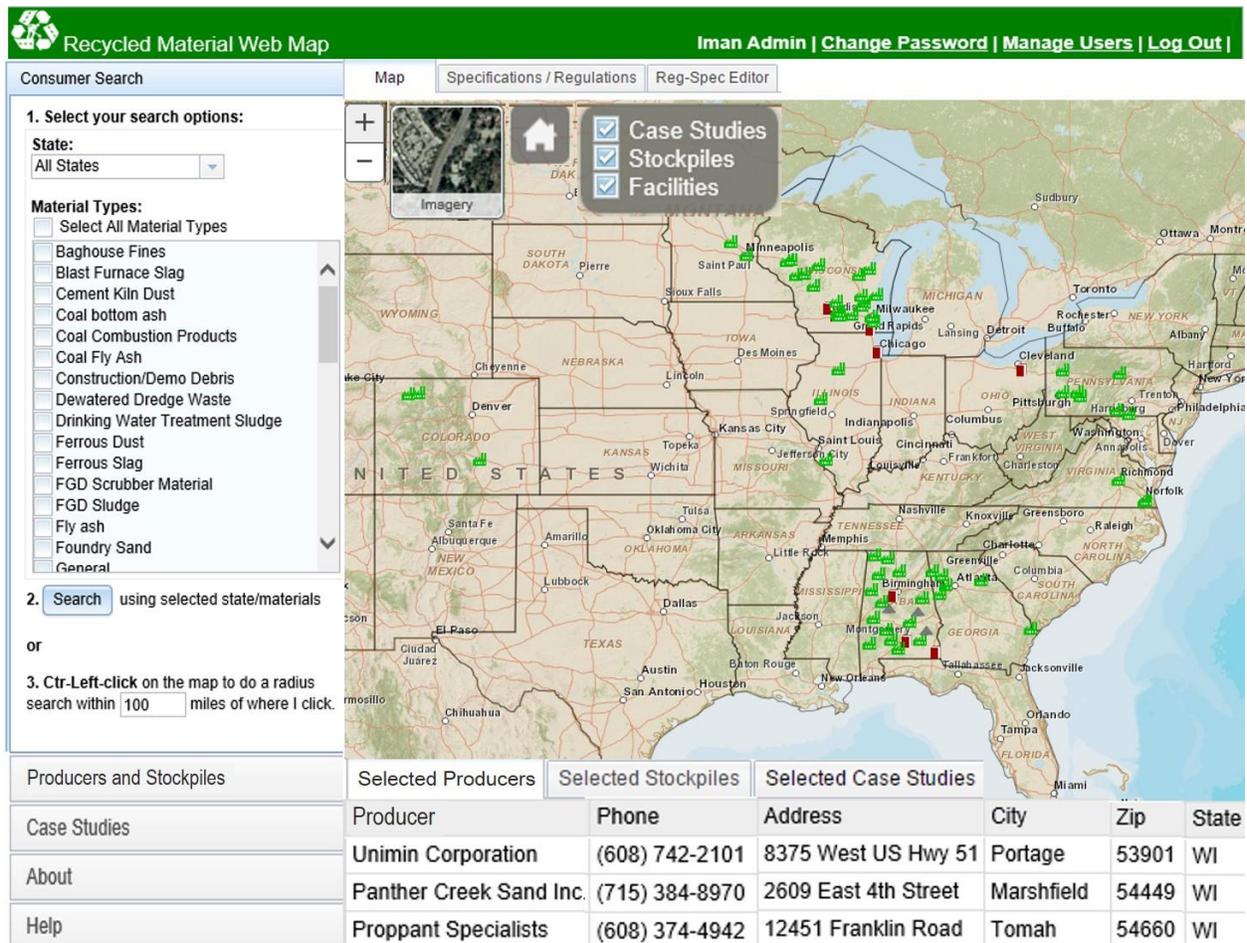


Figure 3.2. Recycled Material Web Map default map view showing the map area with producers, stockpiles, and case studies on an ESRI basemap (ESRI, 2015), the results grid at the bottom of the screen, and a sidebar with multiple panels for searching the site.

3.3.1 General User Level

The general user level is open-access, allowing anyone to view and search the website for recycled material stockpiles, specifications and regulations, and past case studies. There are several ways to search the Recycled Material Web Map. The Consumer Search, as shown in

Figure 3.3(a), allows the user to select a specific state and material type(s) to filter the stockpiles. The stockpiles that meet the search criteria are selected and listed in the grid at the bottom of the main default map screen, as shown at the bottom of Figure 3.2. Clicking on a stockpile in the grid at the bottom of the default map screen, highlights the stockpile on the map, zooms to that stockpile, and a window pops up on the map that displays available quantity information. In addition, a radius search is available that allows a user to locate their construction project and specify a radius in the search panel to select all of the stockpiles that are within the given distance as shown in Figure 3.3(b). Users can toggle between selected stockpiles and selected producers in the results grid at the bottom of the map to view producer contact information and available material quantities.

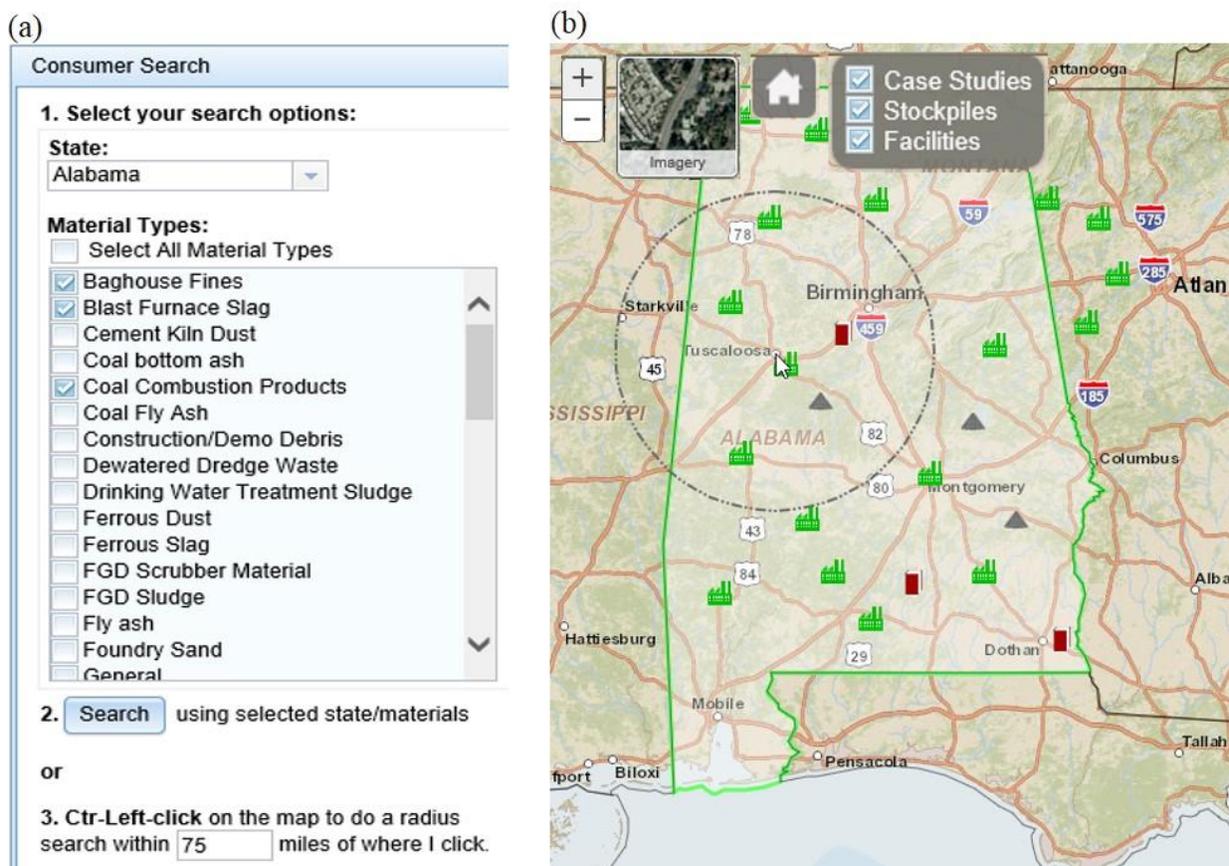


Figure 3.3. (a) Consumer Search panel includes options to search by state and/or material type or search by radius. (b) Radius search selects all producers and stockpiles within a specified radius (ESRI, 2015).

In addition to searching for available stockpiles and viewing producer contact information, general users can also search federal and state DOT specifications and environmental regulations that apply to the beneficial use of recyclable material. The majority of DOTs maintain construction specifications specific to the use of recycled material in roadway construction projects, and the environmental agency of each state regulates the use of recycled material. Any recycled material that is used in construction projects must meet both sets of regulatory requirements, and some practitioners may be unfamiliar with these requirements. Therefore, recycled material specifications and regulations have been collected for national and state entities to provide focused information for users. Specifications and regulations from agencies of seventeen states and federal agencies including AASHTO, FHWA, and EPA have been identified and are included in the Recycled Material Web Map database. To search the specifications and regulations, users can filter by state and/or material on the aforementioned consumer search panel or simply click within a state on the map. The specifications/regulations tab automatically updates based on the search results. As shown in Figure 3.4, links to applicable specifications and regulations are listed on the tab as well as the agency, material type(s), and material application(s). Also, a short description of each specification and regulation appears by hovering over a specification or regulation. Below the specifications and regulations, additional information that pertains to the search criteria is listed. Additional information can include fact sheets about the material, design guidance, and links to external websites that may be helpful when designing or constructing with recycled materials. The specifications, regulations, and additional information connect practitioners with recycled

material resources and documents, but engineers and contractors should still perform due diligence checks.

Map Specifications / Regulations Reg-Spec Editor

Agency Specifications / Regulations

Virginia Department of Transportation (VDOT) **2007 Road and Bridge Specifications**
Division II - Materials

| Specification | Application | Material |
|--|------------------|---------------------|
| 217.02.d Hydraulic Cement Concrete Materials | Coarse aggregate | Blast Furnace Slag |
| 248.02.a Stone Matrix Asphalt Concrete | Asphalt concrete | Reclaimed asphaltic |
| 208.02.a Subbase and Aggregate Base Material | Base aggregate | Blast Furnace Slag |

For Additional Information

| Agency | Additional Information | Applications | Materials |
|---|---|--------------------------|--------------|
| Recycled Materials Resource Center (RMRC) | Foundry Sand - Asphalt Concrete | Asphalt concrete | Foundry Sand |
| Recycled Materials Resource Center (RMRC) | Foundry Sand - Flowable Fill | Flowable fill | Foundry Sand |
| Recycled Materials Resource Center (RMRC) | Foundry Sand - Portland Cement | Portland cement concrete | Foundry Sand |

Figure 3.4. The specifications and regulations tab includes DOT specifications, environmental regulations, and additional information pertaining to the beneficial use of recycled material.

On the default map view, general users are able to view a map of case study projects that have used recycled materials in past projects. Case studies are shown as rectangles on the map tab and can be filtered using the same search panel as the stockpiles, producers, and specifications. Figure 3.5 shows an example of the information that is attributed to each case study including: a brief synopsis of the project, material(s) used, and additional project documentation such as reports or spreadsheets.

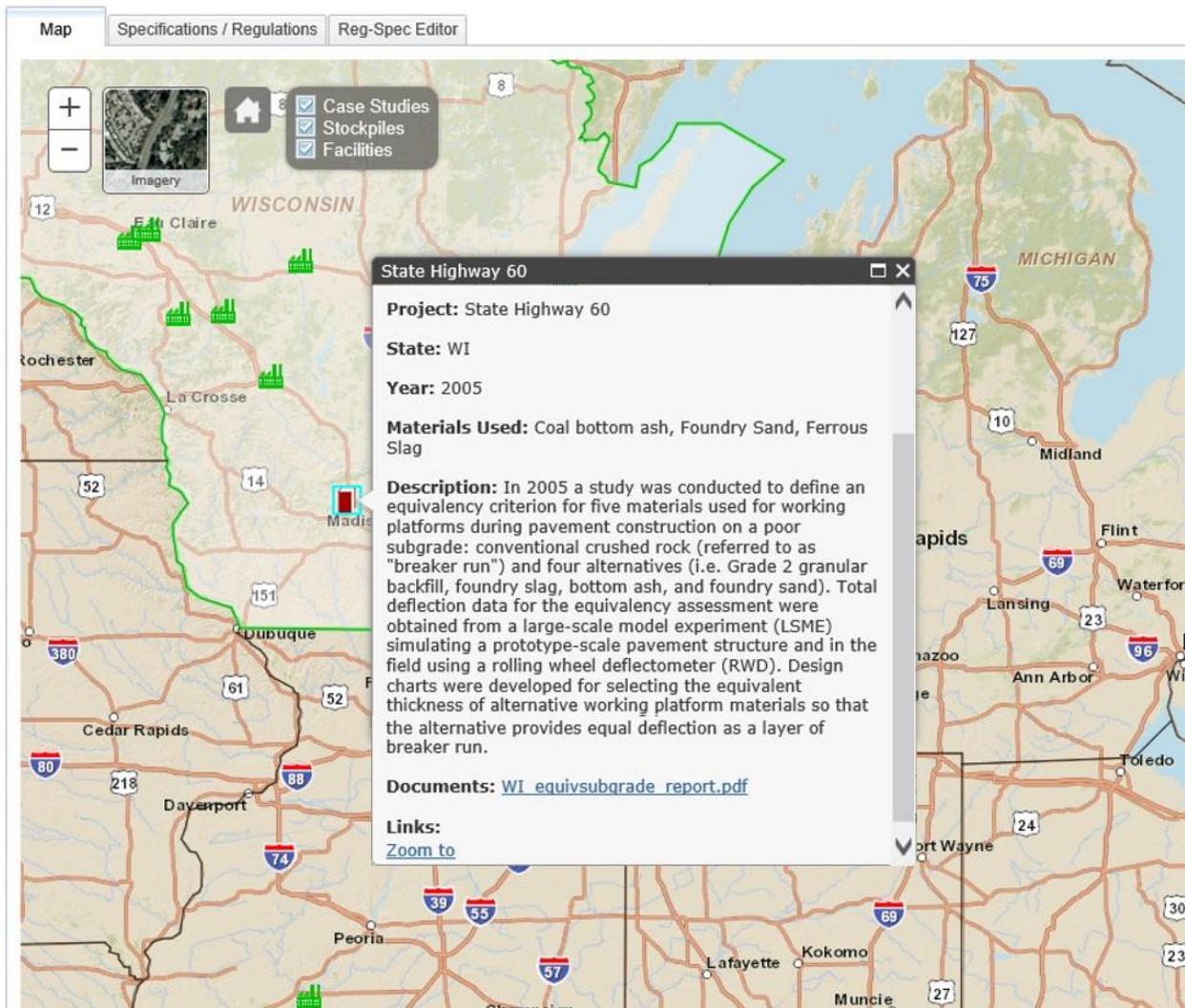


Figure 3.5. Case study synopsis window displays key information including project name, materials used, description, and link(s) to project documentation (ESRI, 2015).

3.3.2 Producer User Level

The producer user level has all of the capabilities of the general user plus several additional mapping privileges. In order to add and update stockpile or producer information, users must create a log-in to the website. Producers who log-in to the site gain access to the producer and stockpile side panel, allowing users to update producer contact information and stockpile information. A new producer can add facility contact information by clicking the “Add New Producer” button and completing the form that pops up. Returning producers can update

the contact information for a facility by clicking the edit button beneath the producer information displayed in the panel as shown in Figure 3.6. Producers are only able to edit their own facility and stockpile information. Optionally, producers can choose to limit what information they include on the site, such as quantity, cost, or composite material constituents, to protect confidentiality.

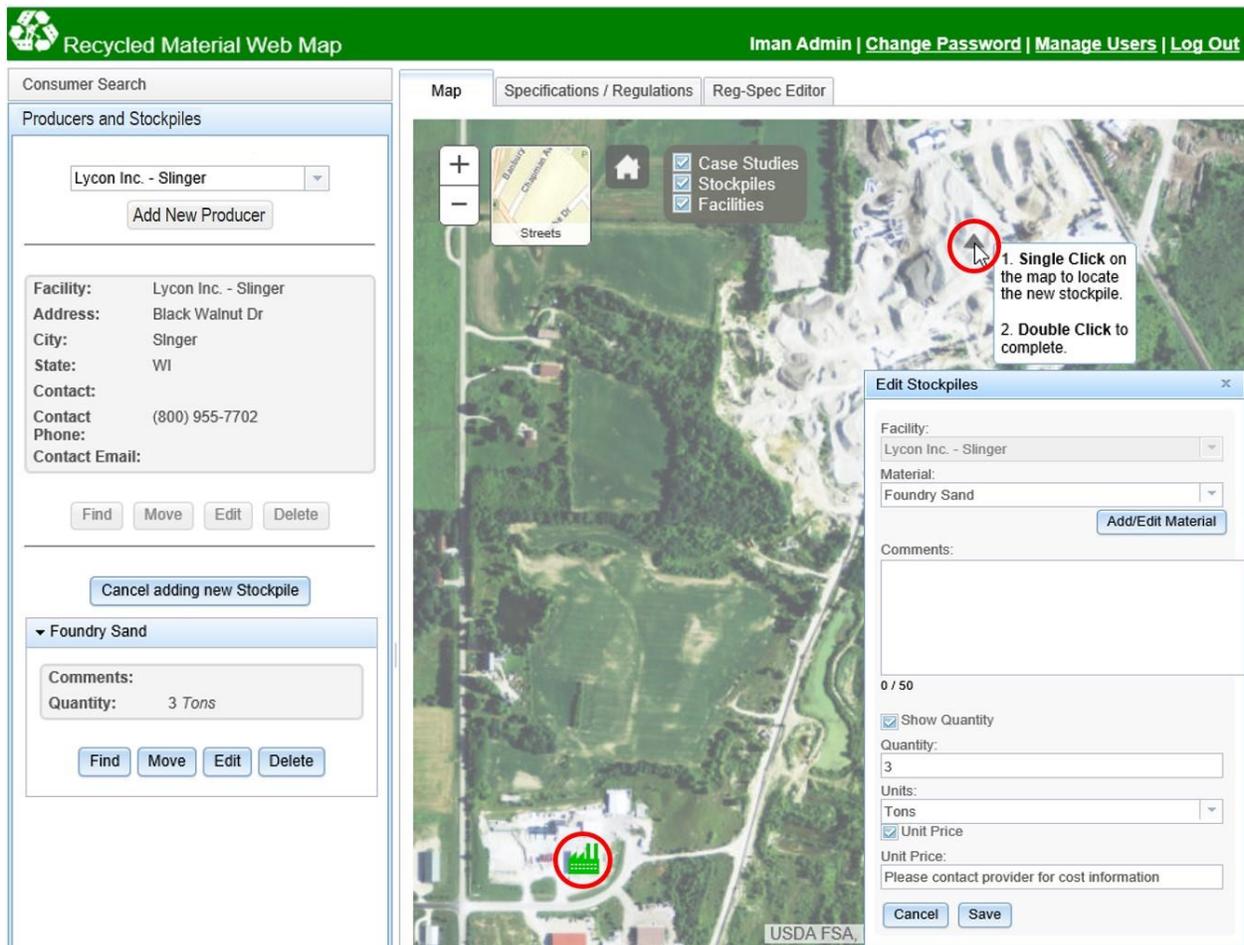


Figure 3.6. Example facility and stockpile (circled in this figure) that are added and updated on the Producers and Stockpiles panel. The stockpile details are listed beneath the Producer contact information (ESRI, 2015).

3.3.3 *Advanced User Level: Researcher/Agency*

Researchers and DOT agencies can receive advanced user login credentials. Advanced users have access to the same website features as the general user and producer user levels, but can also add and edit DOT specifications and regulations and add case studies to the map.

Advanced users can use the Reg-Spec Editor tool to add and edit DOT specifications and regulations. To add or edit a specification, the user selects or adds an agency (DOT), group, and section. The specification group is the title of the regulatory document (e.g. 2007 Road and Bridge Specifications) and the section refers to the subheading of the document that includes the specific specification (e.g. Division II – Materials) as shown in Figure 3.7(a). Clicking the “Add Reg/Spec” button or double clicking the specific specification in the bottom grid will open the Add/Edit Reg/Spec dialog box as shown in Figure 3.7(b). Attributes including specification name, number, a brief description, material(s), and application(s) can be added or edited. Materials and applications that are not already listed in the material and application type lists can also be added. Additional information is added in the same way as the specifications and regulations, but this functionality is located on a similar but separate tab.

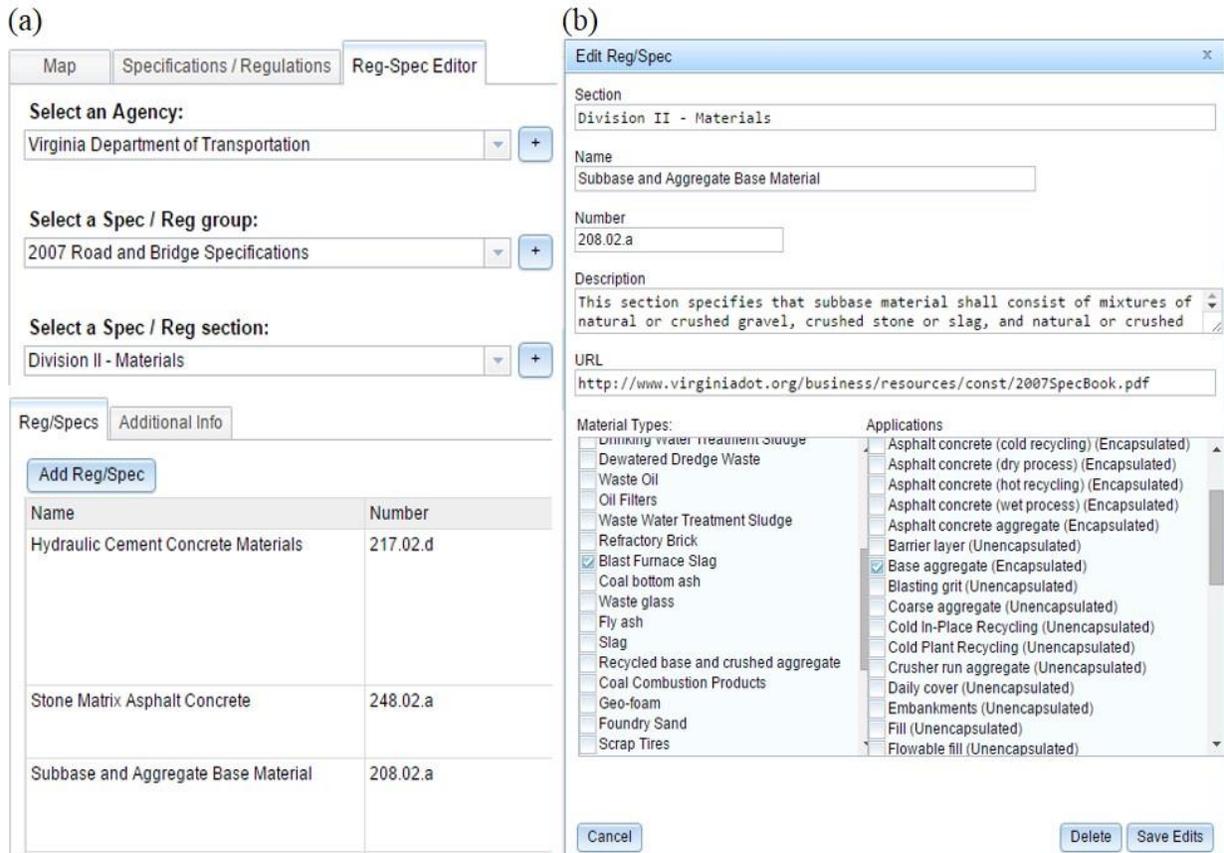


Figure 3.7. (a) Example specifications listed by agency, group, and section in the Recycled Material Web Map Reg-Spec Editor. (b) Reg-Spec Editor dialog box for entering and updating specifications, regulations, and additional information.

In addition to adding specifications and regulations, advanced users can also map case studies and upload documents associated with the project. To add a case study, users can click the “Add New Case Study” button in the Case Studies panel to locate a project on the map and add information into the form as shown in Figure 3.8. Users are prompted to upload any project documentation that might include a final report or mix design. For example, Figure 9 displays a case study on the State Highway 60 project north of Madison, Wisconsin that is currently mapped on the website. The case study includes a list of the recycled materials used, a description of the project, and a link to the project report. Hyperlinks can also be added to case studies and can include links to videos or photographs. This information could increase the

confidence of other practitioners who are considering using recycled material in construction projects by providing useful examples. The case study information is displayed on the Case Studies panel, and can be edited by any advanced user.

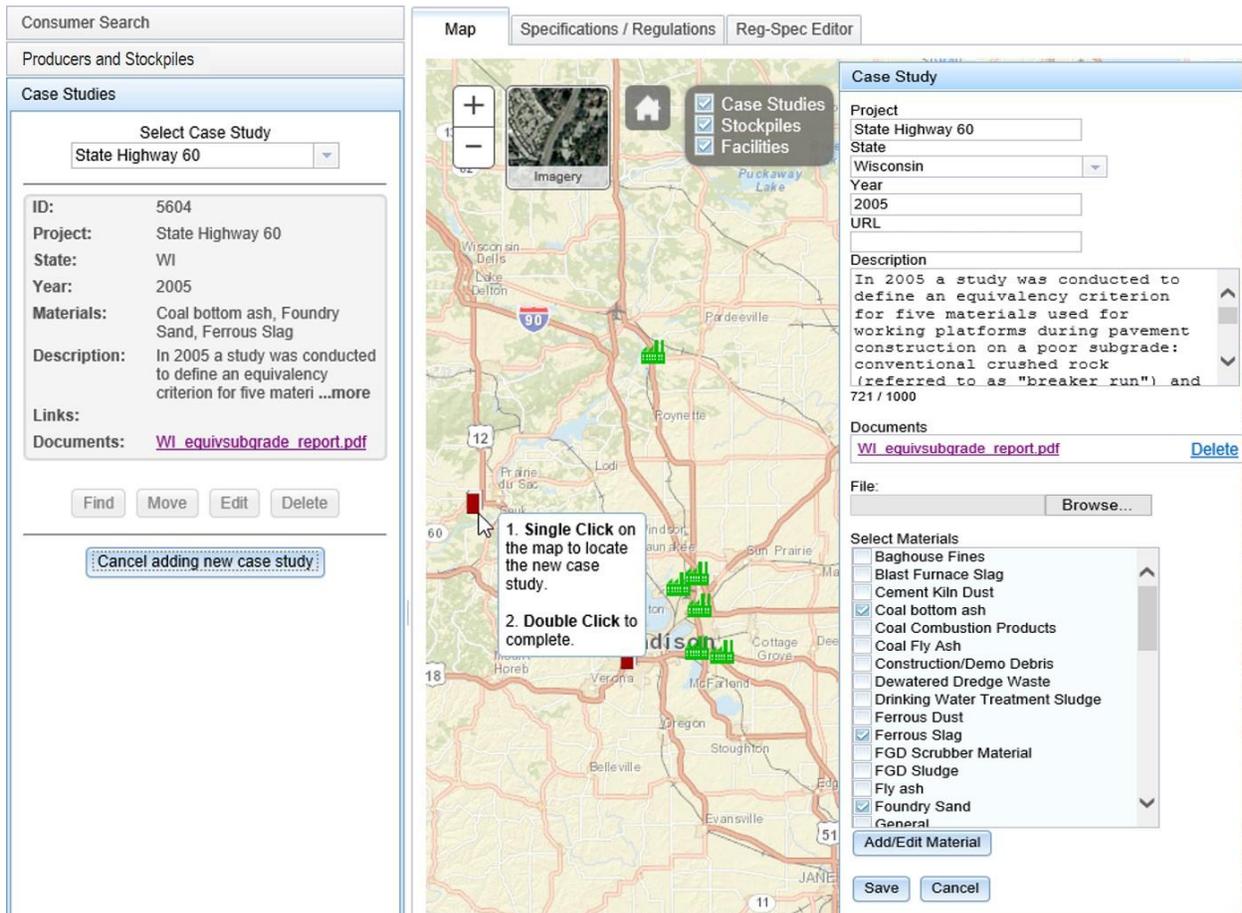


Figure 3.8. Case study data entry form to add and update case study information (ESRI, 2015).

3.4 Quality Assurance and Quality Control

There are web links associated with the Recycled Material Web Map in the regulations, specifications, and case study layers. To avoid “broken links” over time, an automated process routinely checks for changes in the associated page for each link. Hash values created from the source code characters of each page are used in the web page comparisons. If the hash value for

a web page link changes, the Recycled Materials Web Map administrator is notified of the discrepancy and will manually verify that the link is still valid.

3.5 Desktop Routing Tool

Currently the Recycled Material Web Map has limited proximity search functionality, and uses a radius search to identify nearby stockpiles and facilities. In order to expand the location-based search functionality to include driven distance in addition to Euclidean distance, a desktop routing tool was developed using Python scripting. The tool identifies up to five stockpiles proximate to the user's project location and provides a route overview and directions to the nearest stockpile. The tool documentation, script, sample data, and map template are stored in the ESRI recommended Standard Folder Structure (SFS) format and can be easily downloaded and shared. At this time, the tool is a stand-alone script that can be run in a Python console, and it interacts with ArcMap and Google Maps through the `arcpy` and `googlemaps` modules. Because the `googlemaps` module is within a third-party client library, there are additional installation steps that the user must follow before running the tool. Detailed installation instructions as well as the Python code and user guide are included in Appendix B.

3.5.1 Desktop Routing Tool Methodology

The tool was developed in the Scientific PYthon Development EnviRonment (Spyder), which is an interactive development environment (IDE) that is free to download and includes editing, interactive testing, and debugging features (Continuum Analytics, 2016). Users can choose to use Spyder or another IDE to execute the script. The most significant steps in the

script development are explained below. Additional explanations for intermediate steps are included as comments throughout the Python code included in Appendix B.

1. Use raw input to retrieve user-specified workspace and input parameters.

There are several input parameters that the user must enter into the IDE console including workspace, stockpile path, facility path, map document template, project location, and project name. Sample stockpile and facility point shapefiles are included in the desktop routing tool SFS, and eventually current real data could be exported directly from the online Recycled Material Web Map. The project location is entered as an address instead of latitude and longitude coordinates in order to be more user-friendly. The user also specifies the output route shapefile name, and the additional output features are automatically created and located in the workspace.

2. Retrieve project location coordinates from Google Maps and add project location to the map as a point shapefile.

In order to access Google Maps directly from the script, the googlemaps module within the Python client library for Google Maps API Web Services must be downloaded and installed. The Google Maps library provides geocoding which converts addresses into geographic coordinates, and also provides a direction service that calculates directions between locations. The executable file to download the module is included in the desktop routing tool SFS. A user-specific API key is required; therefore, the user needs to generate a key if they do not already have one. The keys are free with a registered Google account, but the service is only free up to a certain point. If the key accesses Google more than a certain number of times in a day, the tool will stop working. Currently, the usage limit is 2,500 requests per day and no more than 10 requests per second, so it is unlikely that the typical use of this script will exceed the limit (Google, 2016).

Once the googlemaps module is installed and the client key is added into the code, the geocode function within googlemaps converts the address of the project entered by the user into geographic coordinates. These coordinates are located within a dictionary, and are easily accessed by using indexing methods.

A new project location point is created by using CreateFeatureClass_management in the arcpy module, and an insert cursor is used to enter the coordinates into the project location table. An update cursor is used to update the fields within the table to add the project name to the table.

3. *Identify the nearest five stockpiles to the project location point.*

The GenerateNearTable_analysis arcpy function is used to find the closest five stockpiles. This function calculates the distance between all of the stockpiles to the project location, and writes the results to a new table. Several optional parameters are included to limit the search radius to 100 miles and only return the closest 5 stockpiles. These are default values that can easily be adjusted within the code. The new table, nearest_5_piles, includes the Euclidean distance from the project location and are ranked in ascending order based on that distance. The Euclidean distance is used by default, but the user can choose to use a geodesic measurement instead which is more accurate for longer distances. The nearest stockpile is selected using the Near_analysis function. Instead of producing a new table, the attributes of the nearest stockpile are appended onto the project location attribute table.

4. *Join tables together to include facility contact information and stockpile names.*

Several joins are performed to connect the facility information to the project location point and the nearest_5_piles table. These joins are all executed using the JoinField_management function.

5. *Generate directions from project location to nearest stockpile.*

The directions function within the googlemaps module generates directions from the project location to the nearest stockpile. The coordinates of the nearest stockpile are retrieved and used in the function. The output of this function is a convoluted dictionary that includes route geometry, step-by-step directions, total distance, and total estimated duration of the trip. Indexing methods and a for loop are used to extract, convert, and print the directions in the Python console in a human-readable format.

6. *Decode the polyline string from the Google Directions output dictionary into a list of coordinates.*

The route geometry is more challenging to decode and convert to a useable format than the step-by-step directions are. There are many open source scripts available that convert the polyline string into a list of coordinates. The open source Google Polyline encoder & decoder was slightly modified and then incorporated into the desktop routing tool code (Villaescusa, 2012). This portion of the code decodes the Google encoded route geometry string using the Google encoded polyline algorithm and returns a list of coordinates for every point along the route.

7. *Convert the coordinate list into route vertices and then create a polyline shapefile to connect the vertices.*

An intermediate point shapefile is created to contain the route vertices using CreateFeatureclass_management. An insert cursor and while loop are used to add the coordinates from the list into the point shapefile. The PointsToLine_management function in arcpy is used to connect the points together with a polyline. This polyline becomes the Shortest Route layer.

8. *Populate template map document and add layers with symbology to the map.*

The template map document includes two existing shapefiles, stockpiles and facilities, and also contains the symbology for the layers created after executing the script: project location, shortest route, and nearest_5_piles table. A map document object is created and the data frames are listed based on the template map document. For each shapefile, a layer is created and added to the data frame, and symbology based on the template is applied to each layer. The document title is populated using the arcpy mapping module and the data frame zoom level adjusts so that the extent of the data frame is centered on the route. The extent will adjust for each new route that is generated with the script.

3.5.2 Desktop Routing Tool Results

The desktop routing tool produces four main outputs: route directions, a table of the nearest five stockpiles, an ArcMap document including all layers, and a route overview PDF document. Figure 3.9 shows an example of the route directions printed in the IDE console. In addition to step-by-step directions directly from Google Maps, the route direction printout includes a total driven distance and an estimated duration of the trip. It is important to note that the estimated duration is calculated based on the road conditions and congestion at the time the script is run; therefore, the actual travel time may vary.

```

Route directions from 1546-1556 Engineering Dr, Madison, WI 53706, USA to W4501 Lime Rd, Eden, WI 53019, USA provided by Google
Map Data.

The total driven distance is 77.9 mi and the estimated duration of the trip is 1 hour 24 mins.
Head east on Engineering Dr toward N Randall Ave
1 min (322 ft)
Turn right onto N Randall Ave
1 min (413 ft)
Turn left onto W Dayton St
1 min (0.2 mi)
Turn left onto N Charter St
1 min (413 ft)
Turn right onto W Johnson St
7 mins (2.3 mi)
Turn right onto N Baldwin St
1 min (0.2 mi)
Turn left onto US-151 N/E Washington AveContinue to follow US-151 N
1 hour 9 mins (71.1 mi)
Turn right onto Co Rd V
1 min (0.2 mi)
Co Rd V turns slightly left and becomes County Rd V
1 min (220 ft)
Turn right to stay on County Rd V
1 min (0.3 mi)
Continue onto Co Rd V
4 mins (3.2 mi)
Turn left onto Lime RdDestination will be on the right
1 min (0.1 mi)

Success, polyline route created. Here is some information about your route shapefile and map document:

File path: D:\RM\MM_Tools\ToolData
File name: route.shp
Shape type: Polyline

Map document path: D:\RM\MM_Tools\ToolData
Map document file: Route_dir.mxd

```

Figure 3.9. Example step-by-step route directions printed in Spyder IDE console.

The nearest_5_piles table includes the five stockpiles that are located closest to the project and are sorted in ascending order by distance as shown in Figure 3.10. The table includes the stockpile ranking based on proximity to the project, geographic coordinates of both the project location and the stockpiles, the type and quantity of material available at each stockpile, and the facility contact information.

| NEAR_RANK | FROM_X | FROM_Y | NEAR_X | NEAR_Y | TYPE | QUANTITY | UNITS | FAC_NAME |
|-----------|------------|-----------|------------|-----------|--------------|----------|-------------|---|
| 1 | -89.327441 | 43.801174 | -88.381886 | 43.703608 | Foundry Sand | 12000 | Cubic Yards | Eden Stone Co. |
| 2 | -89.327441 | 43.801174 | -88.444527 | 44.338477 | RAP | 200 | Tons | Murphy Concrete and Construction Mackville Aggregate Quarry |
| 3 | -89.327441 | 43.801174 | -88.44421 | 44.338694 | RCA | 750 | Tons | Murphy Concrete and Construction Mackville Aggregate Quarry |
| 4 | -89.327441 | 43.801174 | -88.443991 | 44.339018 | Foundry Sand | 15000 | Cubic Yards | Murphy Concrete and Construction Mackville Aggregate Quarry |
| 5 | -89.327441 | 43.801174 | -90.143481 | 44.655734 | Foundry Sand | 2000 | Tons | Panther Creek Sand Inc. |

Figure 3.10. Example nearest_5_piles table displaying the five closest stockpiles to the project location.

An ArcMap map document is created after the script has been run and is located in the Tool Data folder located within the tool SFS. The map document includes all of the layers (project location, stockpiles, facilities, shortest route, nearest_5_piles table) and also displays the ESRI StreetMap basemap as shown in Figure 3.11. In addition, the data frame automatically zooms to the extent of the shortest route and the map can be viewed in either layout view or data view.

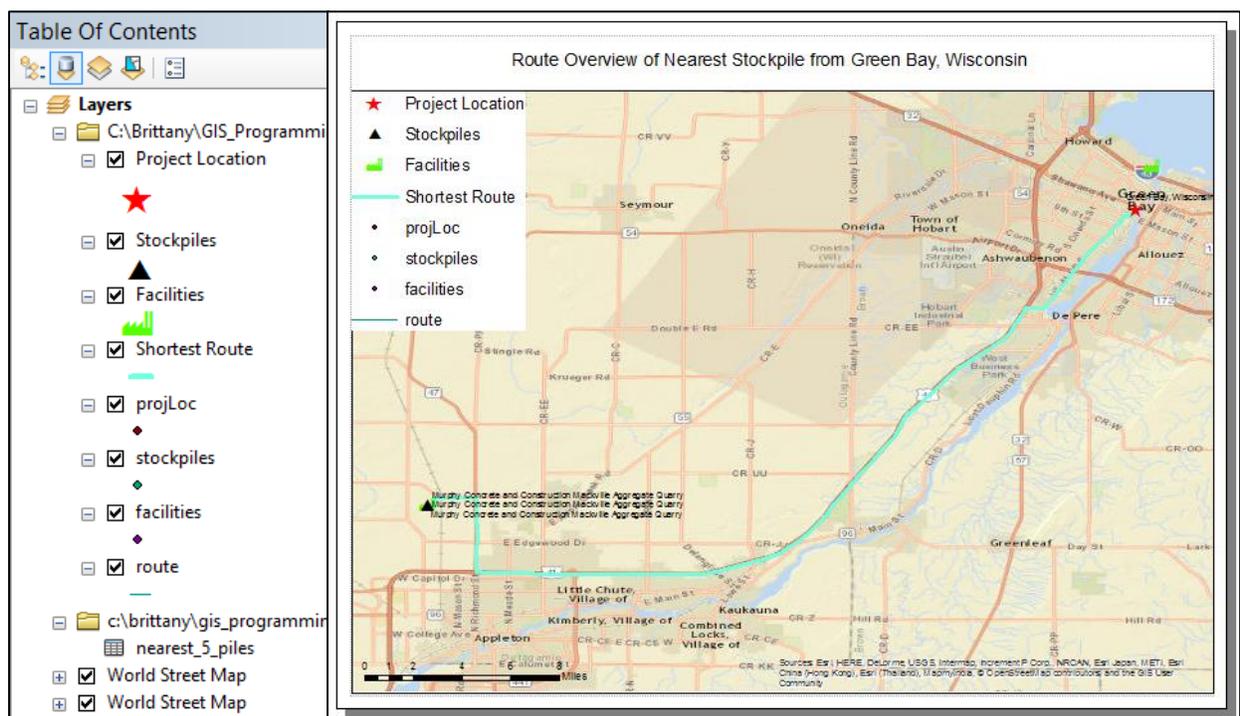


Figure 3.11. Example ArcMap Document generated from RMWM desktop routing tool (ESRI, 2015).

The final output of the Recycled Material Web Map desktop routing tool is a PDF document of the route overview displayed below in Figure 3.12. The PDF is automatically generated and saved in the Tool Data folder within the tool SFS folder. The route overview map is zoomed into the extent of the shortest route, with an additional twenty percent buffer, and includes a legend, title, and scale. The title is automatically generated to include the user-specified project name. The PDF map can be easily printed or shared.

Directions to Nearest Stockpile from Daisy Lane

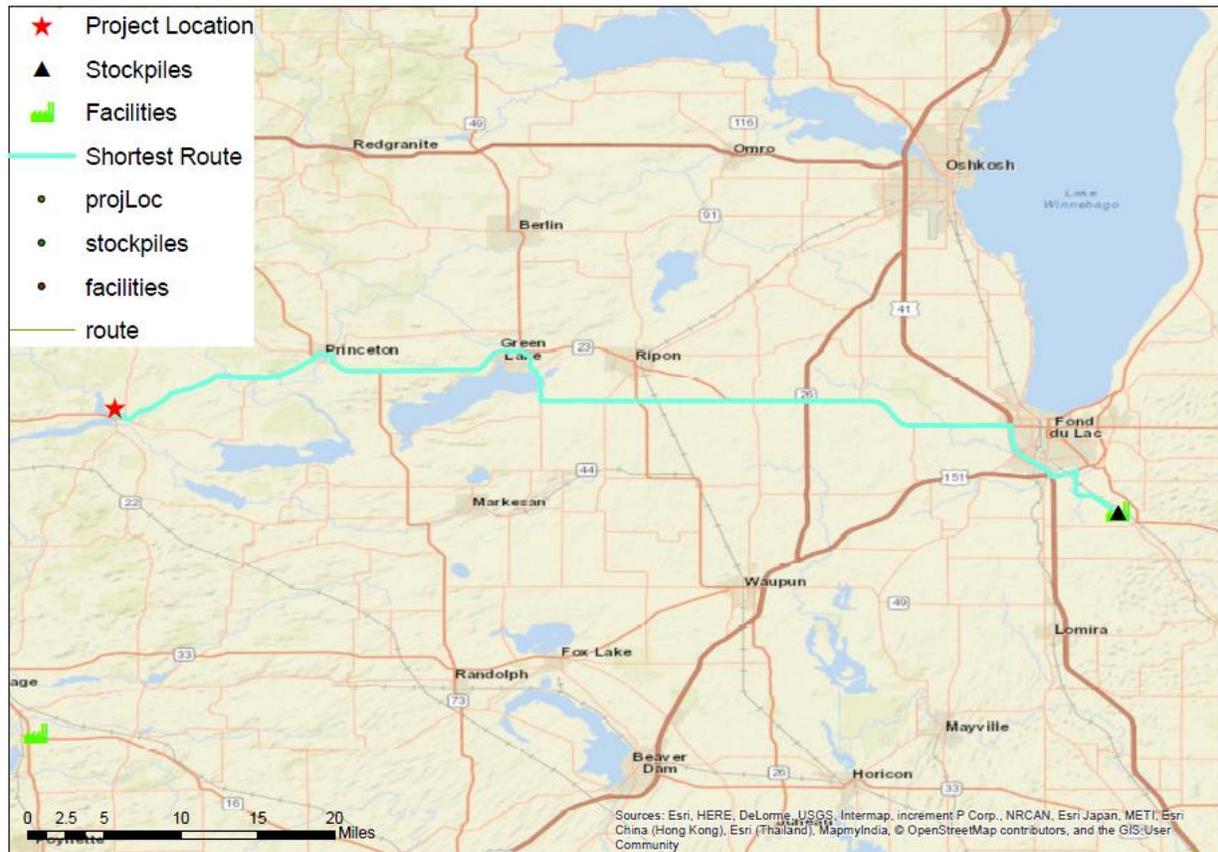


Figure 3.12. Example PDF map generated from the RMWM desktop routing tool (ESRI, 2015).

3.5.3 Desktop Routing Tool Future Work

The Recycled Material Web Map desktop routing tool was developed as a first step towards integrating routing services on the online web map. Using the geocoding and directions modules from the Google Maps client library in the tool code was essential to understanding the functionality and how these services could be integrated into the web map. There are several future tasks that would improve the tool and potentially increase its use.

Adding an “Export to Shapefile” button on the online web map to export all the layers (stockpiles, facilities, case studies, and regulations) will allow users of the routing tool to easily include the most up-to-date data when executing the tool without editing or creating stockpile and facility layers. This functionality will be useful for many other applications and allow users

to download and edit the data to support their research or business needs. In addition, allowing the user to choose material type(s) prior to routing to stockpiles is ideal so that all of the returned stockpiles are potential sources of material for the project. Furthermore, the tool should be able to provide route directions to any or all of the stockpiles listed in the nearest_5_piles table instead of only the closest stockpile to the project. This is especially important if the users seeks multiple material types or requires a quantity that exceeds the volume of an individual stockpile.

Integrating the script into an ArcToolbox will simplify sharing and streamline the use of the tool by removing the necessity to use a Python IDE. Additionally, the tool outputs can be combined by adding the route directions and nearest_5_piles table view to separate data frames within layout view of the ArcMap document. This added capability will greatly enhance the value of the tool outputs, because all of the results will be presented in one place. Overall, the Recycled Material Web Map desktop routing tool complements the proximity search functionality of the online web map by providing automated routing from a project location to the nearest stockpile.

3.6 Conclusion

The methodology presented in this chapter was developed to create the Recycled Material Web Map and corresponding desktop routing tool which provide engineers and contractors a way to advertise and locate recycled material, view applicable regulatory documents, and access case studies where secondary material was successfully utilized. The next chapter, Results, will discuss the current data that has been added to the website, the current status of the tool, and the benefits and broader impacts of this research.

CHAPTER 4

RESULTS

4.1 Current Data

Currently, the Recycled Material Web Map is being populated with producer facility information and stockpile data. There are eighteen registered users, ten material stockpiles, and over eighty facilities that have been added to the website. Some of the facilities and stockpiles have been added by browsing the existing listing-type material exchanges and transferring the applicable information to the Recycled Material Web Map. A new user can request login credentials from the login page. Once approved by the system administrator, the new user can add their facility and stockpile information to the site and add regulatory documents or case studies depending on their user level.

Over 400 specifications and regulations have been collected and integrated into the website for 17 states and 3 national entities (AASHTO, FHWA, and U.S. EPA). Figure 4.1 shows a map that indicates the states that have specifications, regulations, or both entered into the Recycled Material Web Map.

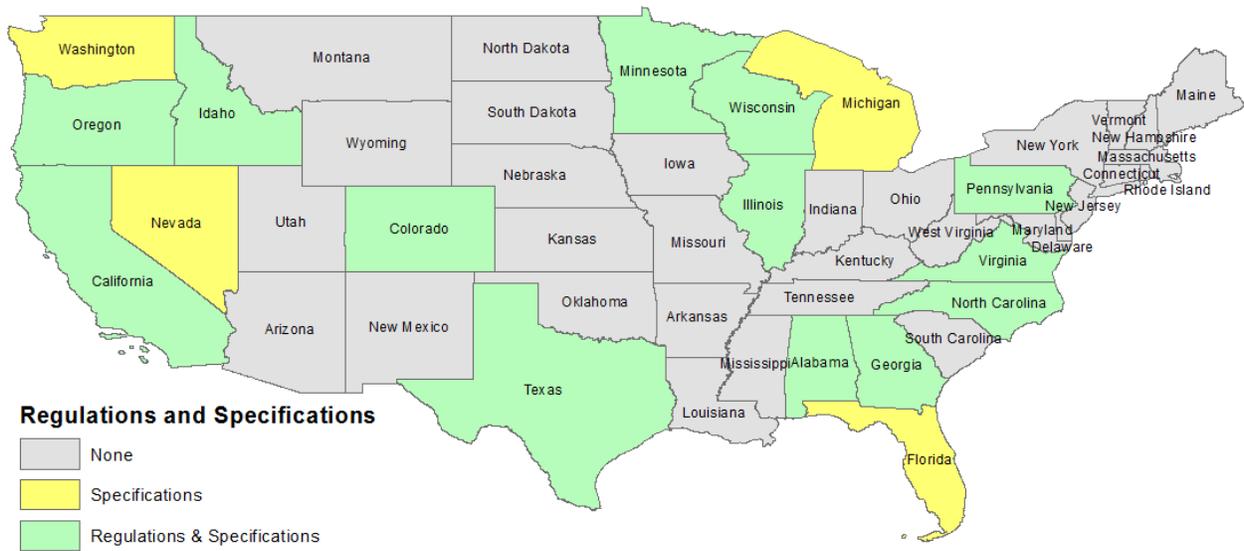


Figure 4.1. States that have regulatory information in the Recycled Material Web Map.

Past construction projects that utilized recycled materials are mapped and documented on the case study layer. Currently, fourteen case studies have been added for projects ranging from bridge replacements and roadway rehabilitation to embankment repairs and building construction. Additional studies will be added as more researchers and DOTs use the website and report successful exchanges of material.

4.2 Current Status

The Recycled Material Web Map was developed and is hosted at the Center for Advanced Public Safety (CAPS) at The University of Alabama and was funded through a pooled fund supporting the Recycled Material Resource Center (RMRC) at the University of Wisconsin-Madison. CAPS coordinates many GIS research projects and has extensive experience developing and maintaining web-based applications, while the RMRC has extensive domain expertise in the area of recycled material. Due to automated quality controls such as automatic emails and the hyperlink hash comparison process, the website is relatively low maintenance and

will evolve mainly based on user input. Because of the autonomous nature of the site, the website can reside on CAPS servers or be migrated to other servers.

The Recycled Material Web Map is flexible and user-defined allowing producers the ability to limit information that is included on the site such as quantity, cost, or composite of material constituents. This flexibility overcomes proprietary issues associated with participation in similar recycled material exchange websites in the past. Also, the specification, regulation, and case study layers are integrated into the website to provide pertinent information to users, thereby increasing traffic to the site and expanding the user base.

4.3 Benefits

The Recycled Material Web Map can be leveraged by both producers and consumers to increase regional sustainability through the use of recycled material. Instead of landfilling recyclable material, producers can offer material and provide key information such as location, company contact, and type of material. By providing consumers a user-friendly map-based interface to find appropriate sources of recycled material closest a project site, the Recycled Material Web Map promotes the use of recycled material and sustainability. The usefulness of the website will continue to increase as more users register and more stockpiles, regulations, specifications, and case studies are added to the map. The Recycled Material Web Map is available at <http://rmwm.caps.ua.edu>.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The Recycled Material Web Map is an all-in-one tool that locates recycled material producers, stockpiles, applicable regulatory information, and case studies using GIS-based data. This single source website has the potential to promote the use of recycled material in construction applications by connecting consumers to producers and providing location, quantity, cost, and contact information. The specification and case study layers render additional functionality with the goal of increasing information availability to users. All users can search stockpiles and producers by state, material type, or within a specified radius. In addition, users can view applicable beneficial reuse specifications and regulations based on the stockpile location, material type, and material applications. Producers can add and update contact information, cost, and material volumes. Advanced users can use the Reg-Spec Editor tool to input DOT specifications, environmental regulations, and additional information concerning recycled materials used in construction applications. Past construction projects that have effectively used recycled materials can be mapped and documented on the case study layer.

5.2 Future Work

Future work will include adding routing capabilities from selected stockpiles to construction sites. A comparison of Google Maps and ESRI web services should be completed in order to determine which API will provide the most functionality for the web map. For

example, each source has varying usage rate thresholds, update frequencies, user support, integration capabilities, and performance speeds. Seamless integration of the routing functionality into the Recycled Material Web Map will greatly increase the benefit of the tool and improve the user experience. Also, estimated transportation costs can be calculated from the driven distance and used to compare several different sources of material.

In addition, an approved recycled material products layer will be added as an additional tab on the web map, similar to the regulations and specifications. State agencies maintain extensive lists of product types and manufacturers that are approved for contractors to use on state projects. For example, a company called EcoStrate creates roadway and ADA signage from low-cost polymer waste materials. The signage is a manufactured product made from recycled materials and has been approved for DOT use in Pennsylvania and California (Pike, 2015; D. Tong, personal communication, June 16, 2015). The web map does not currently have an appropriate place to store this information, so an approved products layer would provide an easy way for contractors to verify or search for sustainable products that are approved in their state. Preliminary approved products information has been collected for the majority of pooled fund states and a database schema has been designed to incorporate this layer into the Recycled Materials Web Map.

Further data will be collected for additional states, in addition to data added by registered users that will accumulate over time. Future phases of the project will work with states in the pooled fund to enter DOT stockpile information, verify or add regulations and specifications, and document case studies. A continued outreach campaign will ensure a strong user base at all three levels for the Recycled Material Web Map.

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APPENDIX A

RECYCLED MATERIAL WEB MAP USER GUIDE

The document contained in this appendix is titled Recycled Material Web Map User Guide and is intended to serve as a step-by-step user's guide that explains the functionality of the Recycled Material Web Map at each user level.

RECYCLED MATERIAL WEB MAP

Map Specifications / Regulations Reg-Spec Editor

| Producer | Contact | Phone | Email | Address | City | State | Zip | Hg |
|----------------------------|---------|----------------|-------|------------------------|------------|-------|-------|----|
| Oak Creek Power Plant | | (414) 571-3291 | | | Oak Creek | WI | 53154 | Pk |
| Valley Power Plant | | (414) 221-2345 | | | Milwaukee | WI | 53233 | Pk |
| Unimin Corporation | | (608) 742-2101 | | 8375 West US Hwy 51 | Portage | WI | 53901 | Pk |
| Fanther Creek Sand Inc. | | (715) 384-8970 | | 2609 East 4th Street | Marshfield | WI | 54449 | Pk |
| Proppant Specialists | | (608) 374-4942 | | 12451 Franklin Road | Tomah | WI | 54660 | Pk |
| Dominion Resources | | (804) 226-9849 | | 2701 Vepco St | Chesapeake | VA | 23323 | Pk |
| O.K. Foundry Company, Inc. | | 804-233-9674 | | 1005 Commerce Road | Richmond | VA | 23224 | Pk |
| TFC Recycling | | (757) 543-5766 | | 1958 Diamond Hill Road | Chesapeake | VA | 23324 | M- |

July 2016

User Guide



The Recycled Material Web Map promotes the use of recycled materials by connecting consumers to producers and providing location, quantity, and contact information. The User Guide will demonstrate the functionality of the website for each user level.

Recycled Material Web Map

USER GUIDE

1.0 INTRODUCTION

This guide will describe the process of using the Recycled Material Web Map, beginning with the privileges given to the general user, followed by producer/facility privileges, advanced user privileges, and finally administrative privileges. Each section of this User Guide will explain the website components that can be utilized by each user level.

1.1 Website Layers

The four layers of the Recycled Material Web Map each provide spatially related information to aid in the use of recycled material in transportation projects. These layers are: producers, stockpiles, specifications/regulations, and case studies.

1.1.1 Producer and Stockpile Layers

The producer layer includes contact information for facilities that produce recyclable material. Facility managers can update material type, application, and quantity information in the stockpile layer. Every stockpile is associated with a producer, but producers are not required to have active stockpiles. Both producers and stockpiles can be designated historic if the material is no longer available or after a period of inactivity. To keep the information current on the website, producers can supply a web service that automatically updates the stockpile quantities. If a service is not available, the producer can be automatically contacted by email to confirm that their stockpile quantities are up to date. If the stockpile information is out-of-date (older than nine months), the stockpile(s) will time out and become historic to ensure quality map data.

1.1.2 Specifications and Regulations Layer

Department of Transportation specifications and environmental regulations that pertain to the beneficial reuse of industrial byproducts or other recyclable materials were collected for six states (Wisconsin, Virginia, Pennsylvania, Minnesota, Illinois, and Georgia) and three federal agencies (American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), and Environmental Protection Agency (EPA)) to populate the regulation and specification layer. Hyperlinks to the specific sections of these regulatory documents at the state and federal agencies are available on the web map and are searchable by state, material, and application.

1.1.3 Case Study Layer

The case study layer locates construction projects that successfully utilized recycled material. In addition to the material type(s) and application(s) used in the project, the additional information stored in the case study layer include a synopsis of the project, pictures, and any other project documentation such as final reports or presentations.

1.2 Website User Levels

There are four user levels associated with the Recycled Materials Web Map: general user, producers or suppliers of recycled material, advanced users, and administrators. These are listed in order of increasing privileges. Each classification has privileges that allow users to perform certain tasks. General users can search for local recycled materials, specifications, and case studies that utilized recycled material in construction projects. Producers can promote material by entering, updating, and maintaining material source information. Additionally, advanced users such as researchers and DOT agencies, can add DOT specifications, environmental regulations, and case studies. The Recycled Material Web Map application was designed to provide specific functionality for each of these four user levels.

2.0 BASIC FUNCTIONALITY

The Recycled Material Web Map was designed as an interactive online tool and supporting website. The website evolves as new producers, stockpiles, and case studies are added.

2.1 Welcome Screen and Login Page

The Recycled Material Web Map is located on a secure server. At the time of this User Guide, the Recycled Material Web Map is located at the following link: <http://rmwm.caps.ua.edu>. Navigate to this address using a web browser to reach the home page.

2.1.1 Welcome Screen

Upon reaching the Recycled Material Web Map home page, a welcome screen will be displayed, as shown in Figure 1. The user has the option to either continue as a general user to view the site, or can log in and gain access to additional features.



Figure 1. The welcome screen gives a brief overview of the site, and allows the user to enter the site as a General User or log in to access additional features.

2.1.2 Login Page

If the “Log In” option is chosen, a Log In window will appear where the user can enter their login credentials as shown in Figure 2. Log in usernames, passwords, and user privileges are created, edited, and managed by the site administrator.



Figure 2. The Log In page allows users to enter login credentials and access additional features of the website.

2.1.3 Request a Login

Requesting a producer login from the login page allows for new users to add their facility and stockpile information to the site (producer level) or add specifications, regulations and/or case studies (advanced user). The site administrator will process the request and notify the user of their login credentials and privileges.

2.2 Default View

Figure 3 displays the default map view of the website underlain by an ESRI basemap that toggles between street view imagery to aerial imagery. Facilities are depicted with factory symbols, stockpiles are shown as triangles, and case studies are represented as rectangles. Users can zoom in and out of the map using the plus or minus buttons located on the top left corner of the map

view or by selecting a state from the drop down menu on the search panel. When a state is selected, the map zooms in to the state level, and users can zoom in further to view a project site by using the plus button or the roller ball of the mouse. Across the top of the default screen are tabs that include: Map, which is the default view; Specifications/Regulations, which displays state and federal information; and Reg-Spec Editor, which allows advanced users to enter and maintain specifications and regulations. The side bar to the left of the map screen includes several panels: Consumer Search, Producers and Stockpiles, Case Studies, and Help. The Consumer Search panel allows users to search for stockpiles, producers, specifications and regulations, and case studies. With appropriate login credentials, facility contact information and stockpile data can be entered on the Producers and Stockpiles panel. Case study information and associated project documents can be uploaded using the Case Studies panel. The result grid at the bottom of the default map screen displays producers, stockpiles, and case studies that are selected based on the search criteria applied in the Consumer Search panel. The map features a user-friendly interface and is accessible on mobile devices.

Recycled Material Web Map Iman Admin | Change Password | Manage Users | Log Out |

Consumer Search Map Specifications / Regulations Reg-Spec Editor

1. Select your search options:

State:

Material Types:

- Select All Material Types
- Baghouse Fines
- Blast Furnace Slag
- Cement Kiln Dust
- Coal bottom ash
- Coal Combustion Products
- Coal Fly Ash
- Construction/Demo Debris
- Dewatered Dredge Waste
- Drinking Water Treatment Sludge
- Ferrous Dust
- Ferrous Slag
- FGD Scrubber Material
- FGD Sludge
- Fly ash
- Foundry Sand
- General

2. using selected state/materials

or

3. Ctr-Left-click on the map to do a radius search within miles of where I click.

| Producers and Stockpiles | Selected Producers | Selected Stockpiles | Selected Case Studies | | | |
|--------------------------|-------------------------|---------------------|-----------------------|------------|-------|-------|
| Case Studies | Producer | Phone | Address | City | Zip | State |
| About | Unimin Corporation | (608) 742-2101 | 8375 West US Hwy 51 | Portage | 53901 | WI |
| | Panther Creek Sand Inc. | (715) 384-8970 | 2609 East 4th Street | Marshfield | 54449 | WI |
| Help | Proppant Specialists | (608) 374-4942 | 12451 Franklin Road | Tomah | 54660 | WI |

Figure 3. Recycled Material Web Map default view showing the map area with producers, stockpiles, and case studies, the results grid at the bottom of the screen, and a sidebar with multiple panels for searching the site.

2.3 About and Help Panels

The About panel gives a brief overview of the site and the features available to each user level.

It also contains links to the Log In page, the Recycled Materials Resource Center, and the User

Guide. Also, the website disclaimer is listed on the About panel. The Help panel includes the User

Guide and several video tutorials of the major components of the website.

3.0 GENERAL USER LEVEL

The general user level is open-access, allowing anyone to view and search the website for recycled material stockpiles, specifications and regulations, and past case studies.

3.1 Search Material Stockpiles and Producers

There are several ways to search the Recycled Material Web Map. The Consumer Search, as shown in Figure 4(a), allows the user to select a specific state and material type(s) to filter the stockpiles. The stockpiles that meet the search criteria are selected and listed in the grid at the bottom of the main default map screen, as shown at the bottom of Figure 3. Clicking on a stockpile in the grid at the bottom of the default map screen, highlights the stockpile on the map, zooms to that stockpile, and a window pops up on the map that displays available quantity information. In addition, a radius search is available that allows a user to locate their construction project and specify a radius in the search panel to select all of the stockpiles that are within the given distance as shown in Figure 4(b). To activate the radius search, enter the desired radius in the third search option in the search panel, and hold the “Ctrl” button on the keyboard and left-click the mouse. The point that is left-clicked will be the center of the radius search. Users can toggle between selected stockpiles and selected producers in the results grid at the bottom of the map view to view producer contact information and available material quantities.

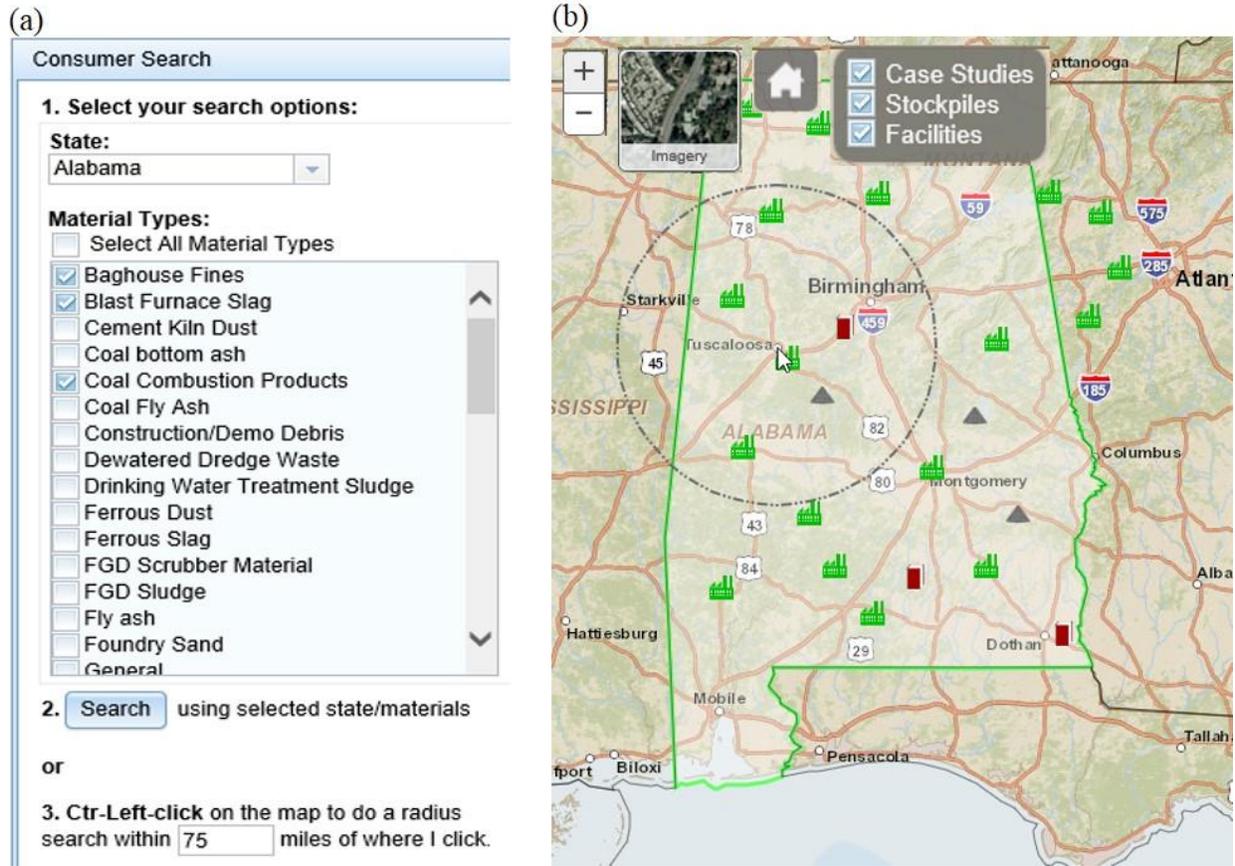


Figure 4(a) Consumer search panel includes options to search by state and/or material type or search by radius. **(b)** Radius search selects all producers and stockpiles within a specified radius.

3.2 Search Specifications and Regulations

In addition to searching for available stockpiles and viewing producer contact information, general users can also search federal and state DOT specifications and environmental regulations that apply to the beneficial use of recyclable material. Specifications and regulations from federal agencies including AASHTO, FHWA, and EPA have been identified and added to the Recycled Material Web Map database. Also, specifications and regulations have been included for several states including: Wisconsin, Virginia, Pennsylvania, Minnesota, Illinois, and Georgia. To search the specifications and regulations, users can filter by state and/or material on the aforementioned consumer search panel or simply click within a state on the map. The specifications/regulations tab automatically updates based on the search results. As shown in Figure 5, links to applicable specifications and regulations are listed on the tab as well as the

agency, material type(s), and material application(s). Also, a short description of each specification and regulation appears by hovering over a specification or regulation. Below the specifications and regulations, additional information that pertains to the search criteria is listed. Additional information can include fact sheets about the material, design guidance, and links to external websites that may be helpful when designing or constructing with recycled materials.

Map
Specifications / Regulations
Reg-Spec Editor

| Agency | Specifications / Regulations | | |
|--|---|--|--|
| Virginia Department of Transportation (VDOT) | 2007 Road and Bridge Specifications Division II - Materials | | |
| | 217.02.d Hydraulic Cement Concrete Materials | <i>Application</i> Coarse aggregate | <i>Material</i> Blast Furnace Slag |
| | 248.02.a Stone Matrix Asphalt Concrete | <i>Application</i> Asphalt concrete | <i>Material</i> Reclaimed asphaltic |
| | 208.02.a Subbase and Aggregate Base Material | <i>Application</i> Base aggregate | <i>Material</i> Blast Furnace Slag |

For Additional Information

| Agency | Additional Information | | |
|---|---|---|----------------------------------|
| Recycled Materials Resource Center (RMRC) | Foundry Sand - Asphalt Concrete | <i>Applications</i> Asphalt concrete | <i>Materials</i> Foundry Sand |
| Recycled Materials Resource Center (RMRC) | Foundry Sand - Flowable Fill | <i>Applications</i> Flowable fill | <i>Materials</i> Foundry Sand |
| Recycled Materials Resource Center (RMRC) | Foundry Sand - Portland Cement | <i>Applications</i> Portland cement concrete | <i>Materials</i> Foundry Sand |

Figure 5. The specifications and regulations tab includes DOT specifications, environmental regulations, and additional information pertaining to the beneficial use of recycled material.

3.3 Search Case Studies

On the default map view, general users are able to view a map of case study projects that have used recycled materials in past projects. Case studies are shown as rectangles on the map tab and can be filtered using the same search panel as the stockpiles, producers, and specifications. Figure 6 shows an example of the information that is attributed to each case study including: a brief synopsis of the project, material(s) used, and additional project documentation such as reports or spreadsheets.

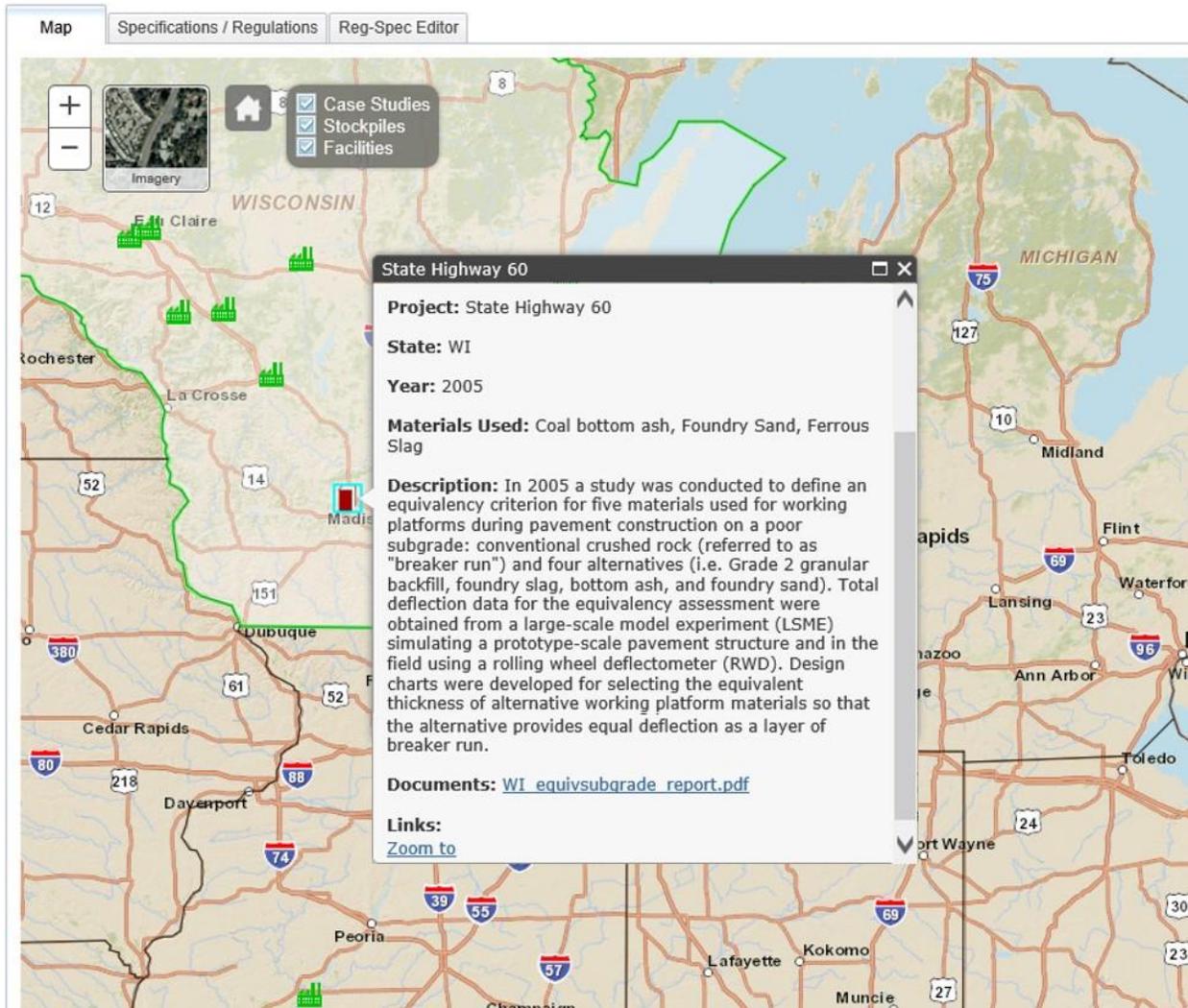


Figure 6. Case study synopsis window displays key information including project name, materials used, and a description.

4.0 PRODUCER USER LEVEL

4.1 Login

The producer user level has all of the capabilities of the general user plus several additional mapping privileges. In order to add and update stockpile or facility information, users must create a log-in to the website. Producers who log-in to the site gain access to the producer and stockpile side panels, allowing users to update producer contact information and stockpile information.

4.2 Add/Edit Producer

A new producer can add facility contact information by clicking the “Add New Producer” button.

To locate the facility, single-click the desired location (can continue to single-click until the exact spot is chosen), and then double-click to place the facility. A window will pop-up where a producer can enter in all applicable contact information. Optionally, users can click the “cancel adding facility” button on the Producer and Stockpile panel to cancel adding the facility.

Returning producers can update the contact information for a facility by clicking the edit button beneath the producer information displayed in the panel as shown in Figure 7.

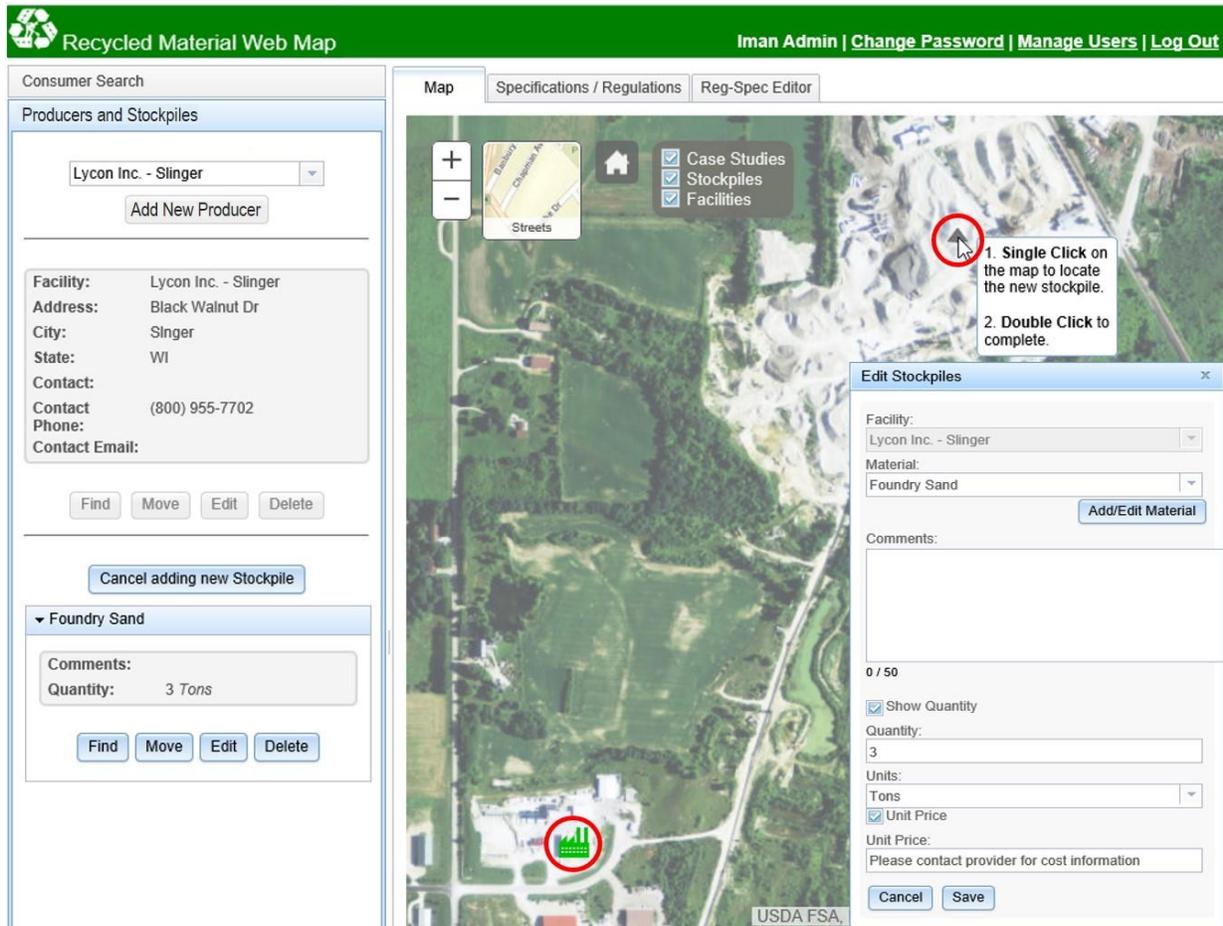


Figure 7. Example facility and stockpile (circled in this figure) that are added and updated on the Producers and Stockpiles panel. The stockpile details are listed beneath the Producer contact information.

4.3 Add/Edit Stockpile

Once a producer has added their facility contact information, the facility can be chosen in the producer drop-down menu on the Producer and Stockpile panel. To add a new stockpile, click the “Add new stockpile” button beneath the facility contact information. Single-click the location of the stockpile on the map (can continue to single-click until the correct spot is chosen), then double-click to confirm the location and place the symbol. A pop-up window will appear where producers can enter all of the applicable stockpile information. To cancel adding a stockpile, click the “cancel adding stockpile” button that appears under the facility contact information. Stockpile information should be updated regularly to reflect up-to-date and accurate volumes. To edit stockpile information, click the “Edit” button that appears underneath the stockpile information on the Producer and Stockpile panel. Producers are only able to edit their own facility and stockpile information. Optionally, producers can choose to limit what information they include on the site, such as quantity or composite material constituents, to protect confidentiality.

5.0 ADVANCED USER LEVEL: RESEARCHER/AGENCY

5.1 Login

Researchers and DOT agencies can receive advanced user login credentials. Advanced users have access to the same website features as the general user and producer user levels, but can also add and edit DOT specifications and regulations and add case studies to the map. Log-in as an advanced user to gain access to the following features.

5.2 Add/Edit Specifications and Regulations

Advanced users can use the Reg-Spec Editor tool to add and edit DOT specifications and regulations. To add or edit a specification, the user selects or adds an agency (DOT), group, and section. The specification group is the title of the regulatory document (e.g. 2007 Road and Bridge Specifications) and the section refers to the subheading of the document that includes the

specific specification (e.g. Division II – Materials) as shown in Figure 8(a). Clicking the “Add Reg/Spec” button or double clicking the specific specification in the bottom grid will open the Add/Edit Reg/Spec dialog box as shown in Figure 8(b). Attributes including specification name, number, a brief description, material(s), and application(s) can be added or edited. Materials and applications that are not already listed in the material and application type lists can also be added. Additional information is added in the same way as the specifications and regulations, but this functionality is located on a similar but separate tab.

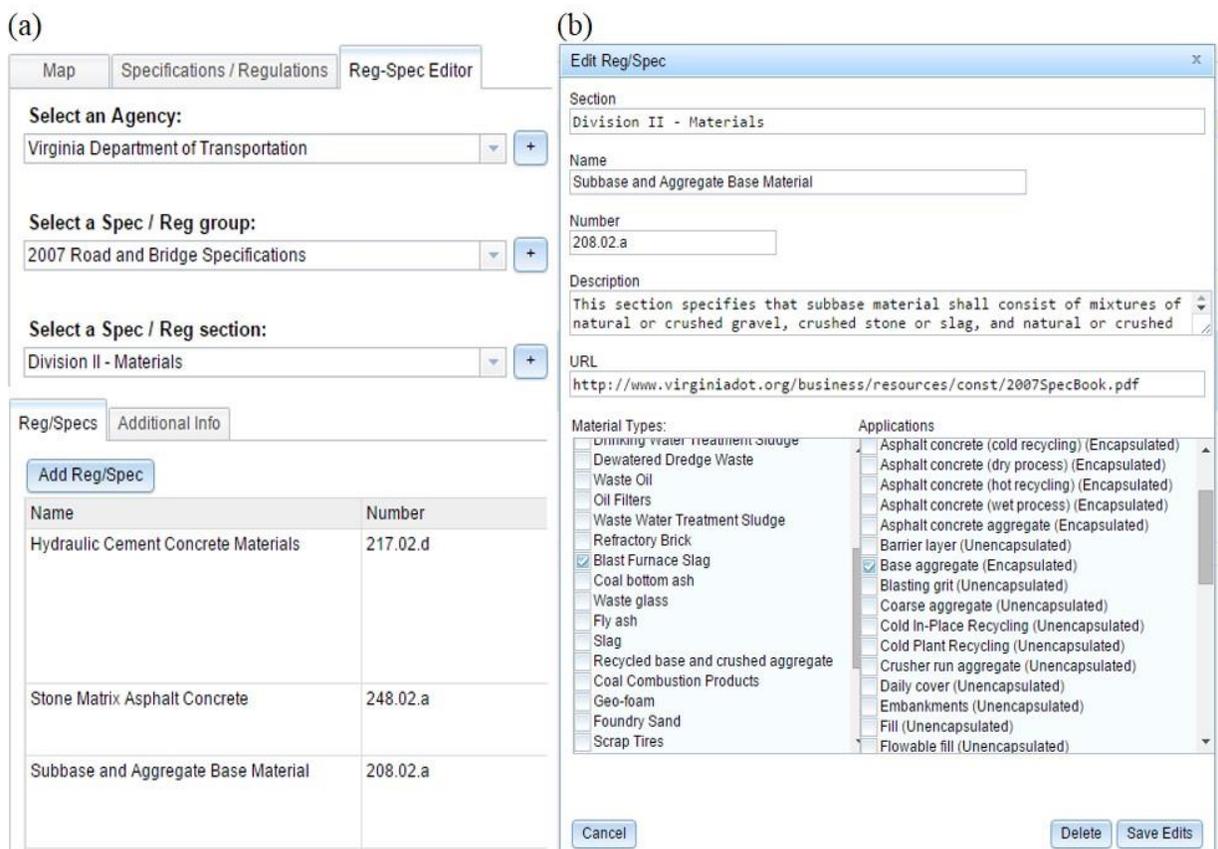


Figure 8(a). Example specifications listed by agency, group, and section in the Reg-Spec Editor. **(b)** Reg-Spec Editor dialog box for entering and updating specifications, regulations, and additional information.

5.3 Add/Edit Case Studies

In addition to adding specifications and regulations, advanced users can also map case studies and upload documents associated with the project. To add a case study, users can click the “Add New Case Study” button in the Case Studies panel to locate a project on the map and add

information into the form as shown in Figure 9. To locate a case study, single-click the project location (can continue to single-click until the correct location is chosen), and then double-click to confirm the location and place a symbol. A pop-up window will appear where any applicable information about the project can be entered. Users are prompted to upload any project documentation that might include a final report or mix design. The case study information is displayed on the Case Studies panel, and can be edited by any advanced user. To edit a case study, click the “edit” button directly under the case study information on the case study panel.

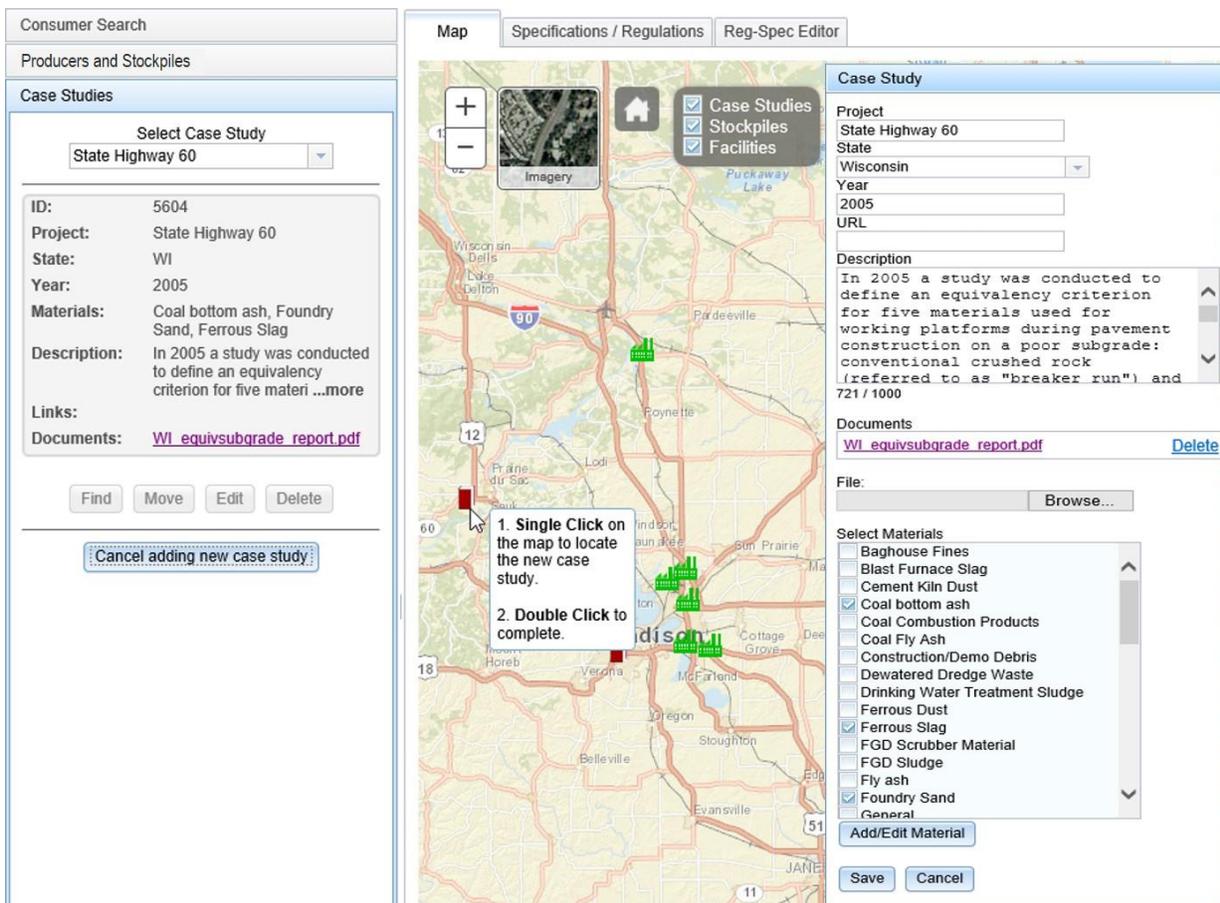


Figure 9. Case study data entry form to add and update case study information.

6.0 ADMINISTRATOR USER LEVEL

An administrator user has all of the privileges available to a general user, producer, or an advanced user, plus additional management privileges. An administrator will create, delete, and modify user names, passwords, and user levels. A Recycled Material Web Map user must contact the administrator to create a user name and password. In addition to managing login credentials, an administrator will oversee all the data entered into the producer, stockpile, specification/regulation, and case study layers. The administrator has the right to remove any inaccurate or inappropriate information that is added to the site without prior notification.

6.1 Create/Edit User Privileges

Administrators can create and edit user privileges through the “Manage Users” button located in the top right corner of the website screen as shown in Figure 10.



Figure 10. Header ribbon including the Manage Users button.

Once the “Manage Users” button is selected, a dialog box will open. The administrator can either enter a username to edit privileges of an existing user, or click the “Add New User” button to create a new username and privileges. Figure 11 shows the initial Manage Users window.

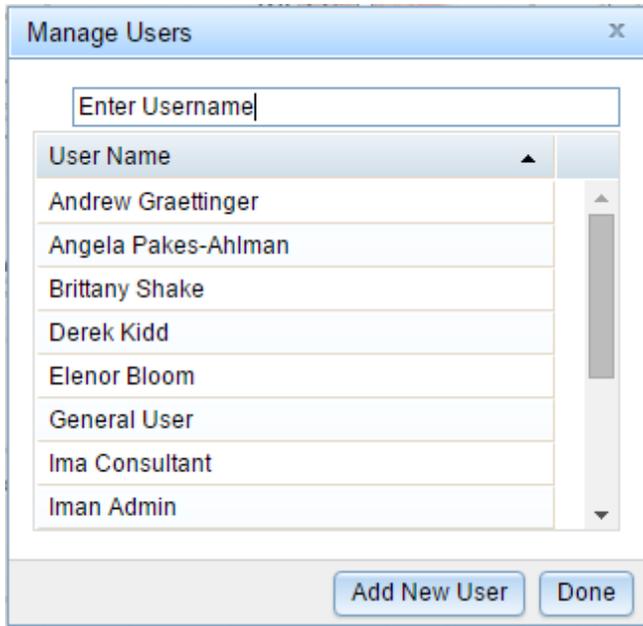


Figure 11. Manage Users window

To add users, select the “Add New User” button. A separate pop up window will replace the existing Manage Users window and provide blank fields for new user information to be entered as shown in Figure 12. Multiple roles can be selected for each user. After all of the information has been entered, select the “Add User” button at the bottom of the window to add the user.

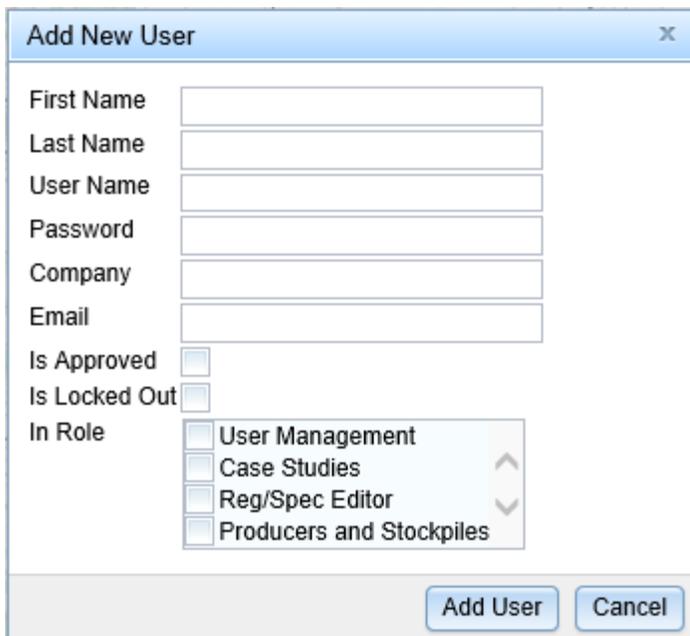


Figure 12. Add New User entry window.

User information can be updated by an administrator by clicking on the “Manage Users” button on the header ribbon (Figure 10) which opens the Manage Users window (Figure 11). The Manage Users window displays a full list of users. A user can be selected by searching using the search option (“Enter Username”) or by scrolling down the list and clicking directly on the user name. Once a user has been selected, an additional screen will appear containing the user’s current information displayed in Figure 13. The administrator may edit any of the fields as necessary, then click the “Update User” button to save the information to the website. Click the “Done” button to close the Manage Users window.

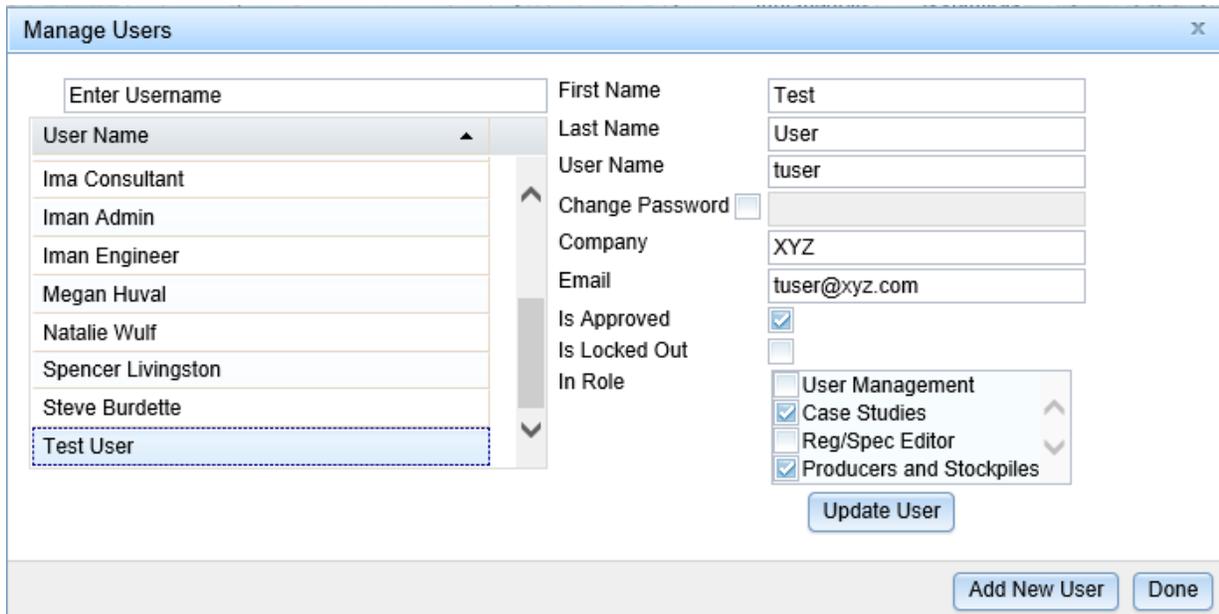


Figure 13. Manage Users window to edit existing user information.

7.0 ERROR REPORTING

Please contact the site administrator through the Help panel to report an error. The Help panel includes a section entitled “Submit Bug Report” that can be used to notify the site administrator of any unexpected behavior while using the website. To submit a bug report, users should click on the “Submit Bug Report” button as shown in Figure 14(a). A dialog box will open allowing the user to enter contact information and a description of the unexpected behavior. Clicking the “Submit” button on the dialog box will send a notification to the site administrator, and the administrator will begin to resolve the issue. In some cases, the administrator may contact the user directly to request more details about the unexpected behavior of the website.



Submit Bug Report x

User Name:

Email Address:

Please include the following:

- Description of unexpected behavior
- All actions that caused the bug to occur

Reminder: The more accurate the description of the steps taken to cause this bug, the easier it will be for us to resolve the issue.

0 / 1000

Figure 14(a). Submit Bug Report section located on the Help panel. **(b)** The Submit Bug Report dialog box allows users to enter contact information and a description of unexpected website behavior.

APPENDIX B

DESKTOP ROUTING TOOL

This document includes a compilation of the Recycled Material Web Map Routing Tool Python Code, Installation Instructions, and the User Guide.

CONTENTS

| | |
|--------------------------------|----|
| INSTALLATION INSTRUCTIONS..... | 64 |
| USER GUIDE..... | 69 |
| PYTHON CODE | 76 |

INSTALLATION INSTRUCTIONS

Latest Update: April 27th, 2016

1. Download the RMWM_Tools compressed folder.
2. Unzip the folder to your hard drive for faster performance. Folder structure should look like Figure 1.

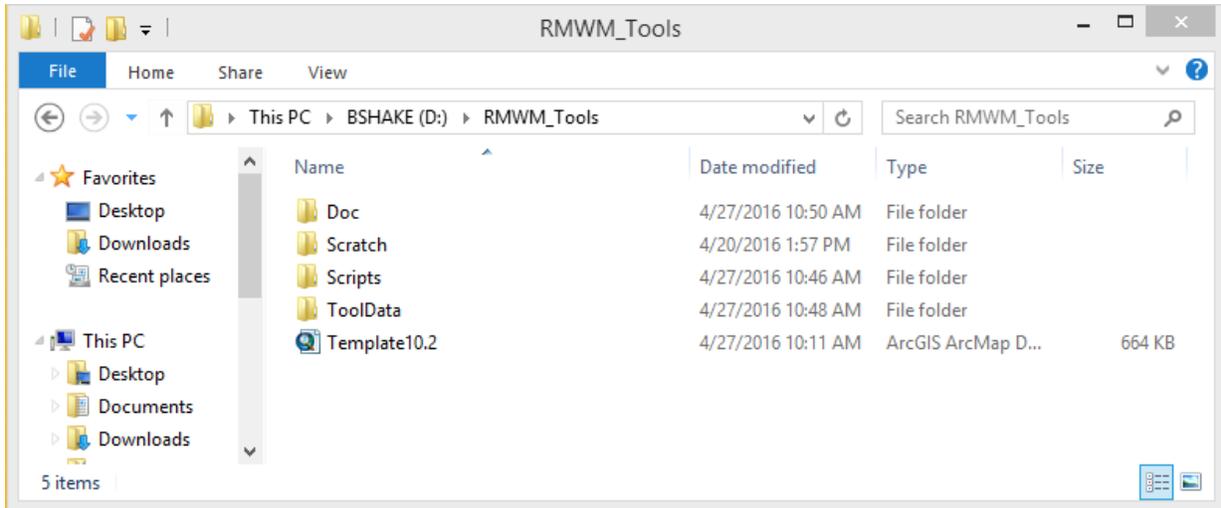


Figure 1. RMWM_Tools folder structure

3. Double-click the Scripts folder to view the scripts and client libraries, as shown in Figure 2.

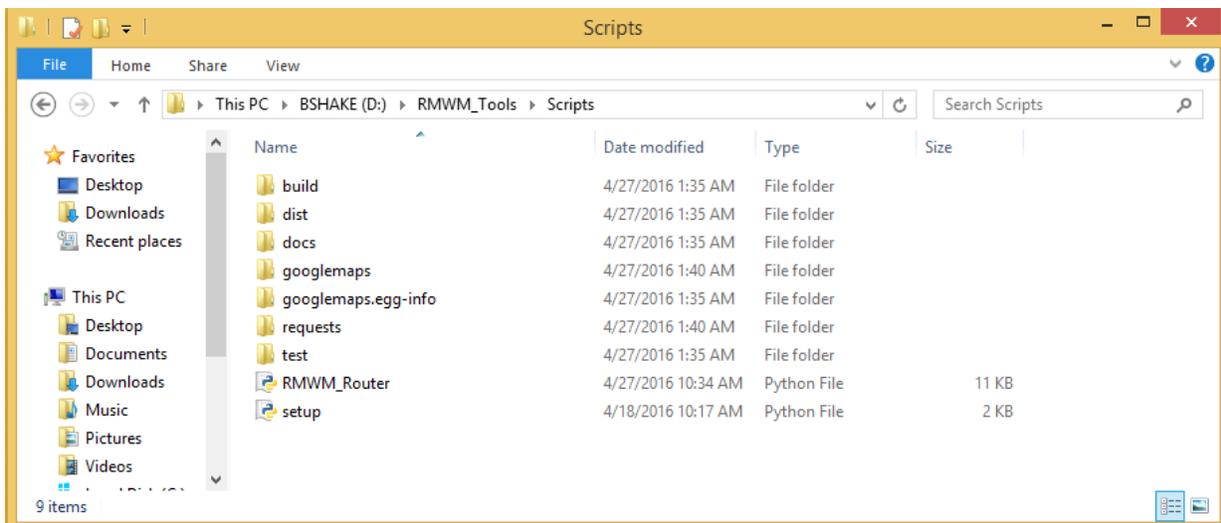
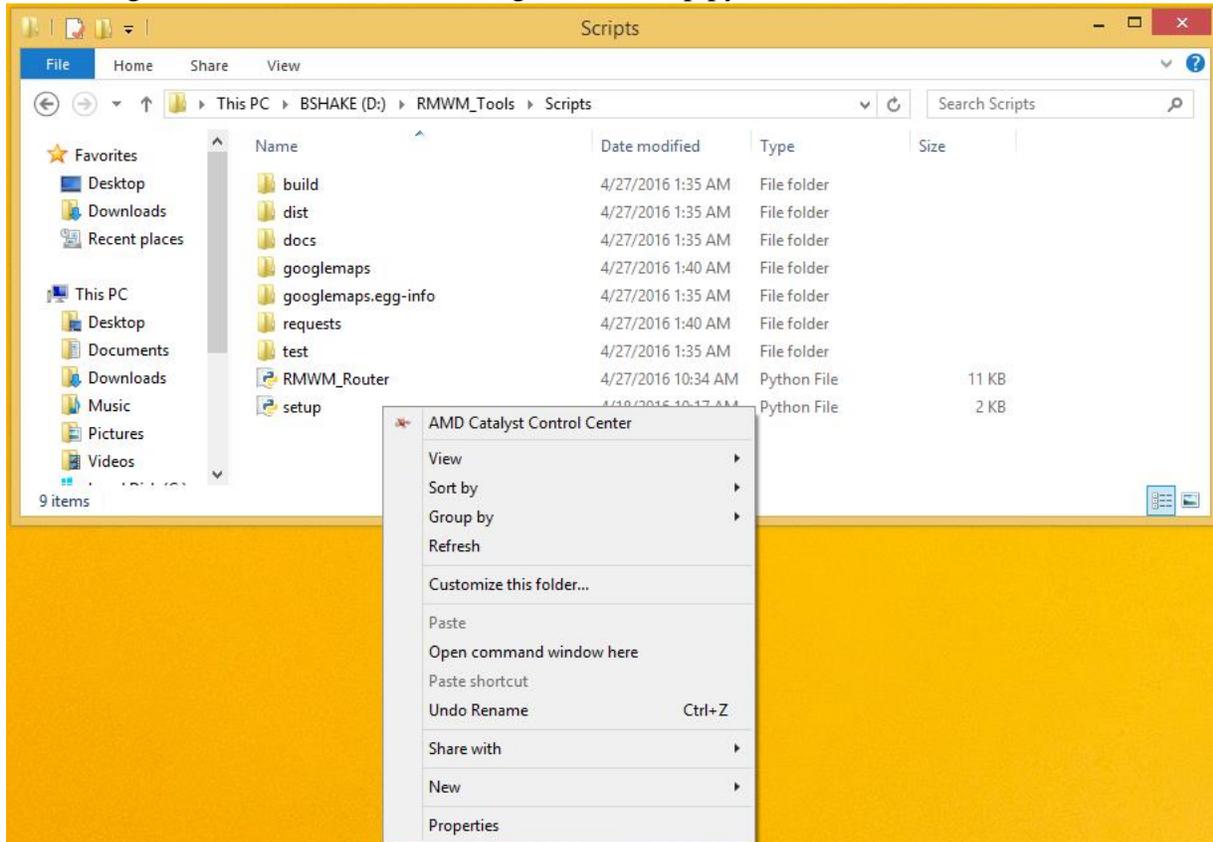


Figure 2. Scripts folder containing scripts and third-party client libraries

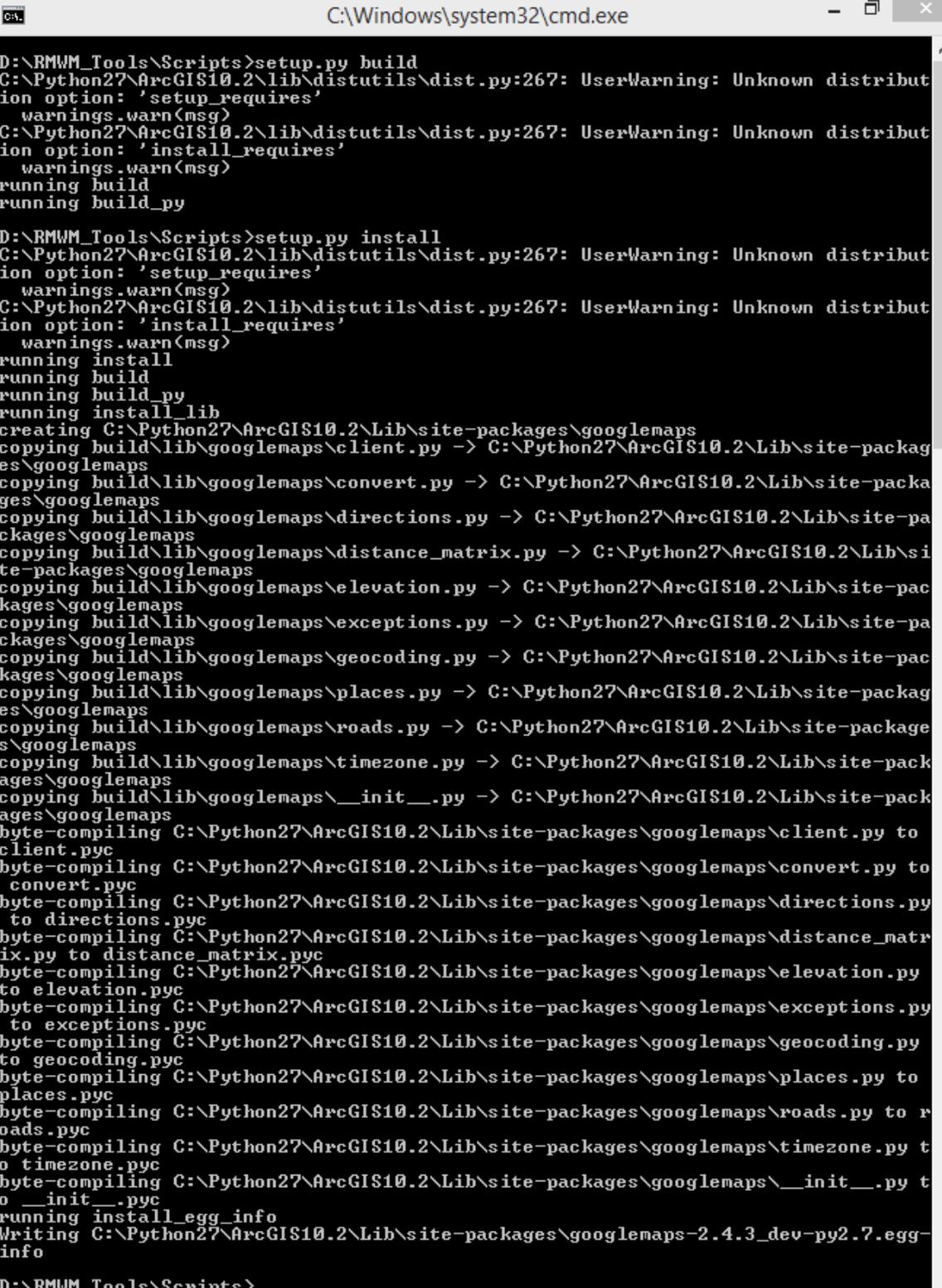
4. Hold down the shift key and right-click on the setup.py file, as shown in Figure 3.

Figure 3. Hold down shift and right-click setup.py



5. Click "Open command window here" to open the command prompt.
6. Type "setup.py build" and press enter.

7. Type “setup.py.install” and press enter to install the library, as shown below in Figure 4.



```
C:\Windows\system32\cmd.exe
D:\RMWM_Tools\Scripts>setup.py build
C:\Python27\ArcGIS10.2\lib\distutils\dist.py:267: UserWarning: Unknown distribution option: 'setup_requires'
  warnings.warn(msg)
C:\Python27\ArcGIS10.2\lib\distutils\dist.py:267: UserWarning: Unknown distribution option: 'install_requires'
  warnings.warn(msg)
running build
running build_py

D:\RMWM_Tools\Scripts>setup.py install
C:\Python27\ArcGIS10.2\lib\distutils\dist.py:267: UserWarning: Unknown distribution option: 'setup_requires'
  warnings.warn(msg)
C:\Python27\ArcGIS10.2\lib\distutils\dist.py:267: UserWarning: Unknown distribution option: 'install_requires'
  warnings.warn(msg)
running install
running build
running build_py
running install_lib
creating C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\client.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\convert.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\directions.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\distance_matrix.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\elevation.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\exceptions.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\geocoding.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\places.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\roads.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\timezone.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
copying build\lib\googlemaps\__init__.py -> C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\client.py to client.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\convert.py to convert.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\directions.py to directions.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\distance_matrix.py to distance_matrix.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\elevation.py to elevation.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\exceptions.py to exceptions.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\geocoding.py to geocoding.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\places.py to places.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\roads.py to roads.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\timezone.py to timezone.pyc
byte-compiling C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps\__init__.py to __init__.pyc
running install_egg_info
Writing C:\Python27\ArcGIS10.2\Lib\site-packages\googlemaps-2.4.3_dev-py2.7.egg-info
D:\RMWM_Tools\Scripts>
```

Figure 4. Install googlemaps library using the command prompt window

8. Open Spyder
9. Navigate to Tools > PYTHONPATH manager
10. Click “Add path”
11. Add the three paths shown below in Figure 5.

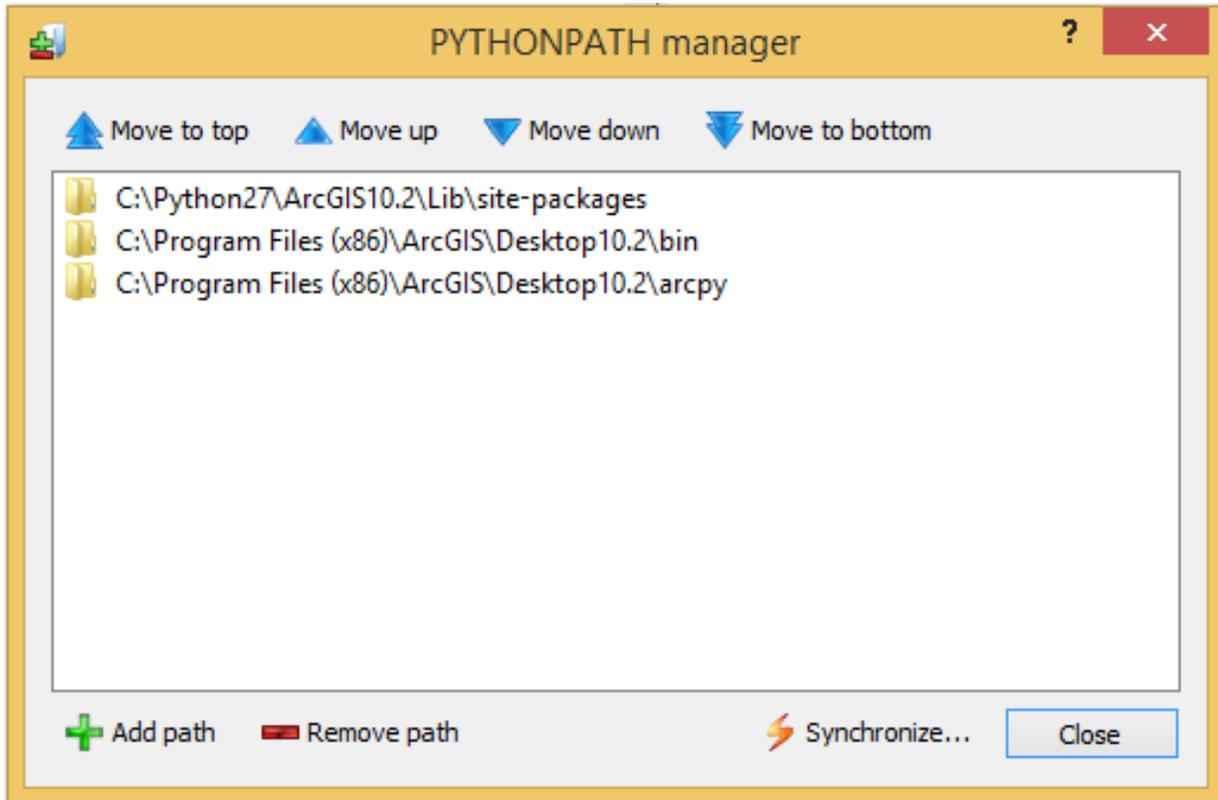


Figure 5. PYTHONPATH manager including the files to be synchronized

12. Click “Synchronize” and choose “Yes” when prompted to clear contents before adding Spyder’s path list as shown in Figure 6.



Figure 6. Synchronize pop-up window, click yes

13. Restart the Spyder console by clicking the orange triangle and then the green arrow at the top left of the console window.

14. Test the installation by typing the following in interactive mode:

```
>>>import arcpy
```

```
>>>import googlemaps
```

15. If an error message doesn't appear, and the functions of both modules have been imported, then the installation is complete and the RMWM Routing Tool is ready to be run.

RECYCLED MATERIAL WEB MAP ROUTING TOOL

User Guide

Consumer Search

1. Select your search options:

State:
No State Selected

Material Types:
 Select All Material Types
 Waste glass
 Fly ash
 Slag
 Recycled base and crushed aggregate
 Coal Combustion Products
 Geo-foam
 Foundry Sand
 Scrap Tires
 FGD Sludge
 Cement Kiln Dust
 Lime Kiln Dust
 Iron Slag
 Ferrous Slag
 Ferrous Dust
 Scrap Metal

2. using selected state/materials

or

3. Ctr-Left-click on the map to do a radius search within 100 miles of where I click.

Producers and Stockpiles

| Case Studies | Producer | Contact | Phone | Email | Address | City | State | Zip | Hours |
|--------------|-----------------------|---------|----------------|-------|---------------------|-----------|-------|-------|-------------|
| | Oak Creek Power Plant | | (414) 571-3291 | | | Oak Creek | WI | 53154 | Please call |
| | Valley Power Plant | | (414) 221-2345 | | | Minwaukee | WI | 53233 | Please call |
| | Unimin Corporation | | (608) 742-2101 | | 8375 West US Hwy 51 | Portage | WI | 53901 | Please call |

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Latest Revision: April 27th, 2016

Before running the script (Requirements):

- Make sure that you have read and followed the installation instructions located in the Doc folder in the RMWM_Tools folder. The tool will NOT run without the successful installation of googlemaps and arcpy.
- Need ArcGIS Advanced Desktop license

Run the script:

1. Open Spyder
2. Navigate to the RMWM_Tools folder in the file explorer
3. Expand the Scripts folder
4. Double click the RMWM_Router.py file to open it in the Editor
5. Click the green “Run” arrow
6. When prompted to locate the ToolData folder, simply click and drag the “ToolData” folder into the console
 - ****Remove the r’ from the front of the path name and the other ‘ at the end of the path name and make sure there is no space after the colon**
 - Click Enter on keyboard
7. Similarly, drag and drop the stockpiles.shp file and the facilities.shp file into the console when prompted
 - ****Again, remove the r’ from the front of the path name and the other ‘ at the end of the path name and make sure there is no space after the colon**
 - Click Enter on keyboard
8. Choose the name and location of the output route polyline shapefile
 - Use the up arrow on the keyboard to get the path that you entered last, and change the name from “facilities.shp” to “route.shp”
 - Make sure that this path is inside your ToolData folder
 - Highly recommended that you use the exact name “route.shp”, and delete any previous versions of the shapefile (excluding the layer file) before running the tool each time
 - Click Enter on keyboard
9. Locate the template map document path by dragging and dropping the “Template_10.2.mxd” file from the RMWM_Tool folder into the console

- ******Again, remove the r' from the front of the path name and the other ' at the end of the path name and make sure there is no space after the colon
- Click Enter on keyboard
- Note: You must use this template for the symbology and route overview to work correctly. Do not create a new blank MXD file.

10. Enter the address of the project location

- Format should be: Street Address, City, State, Zip
- Note: The project should be no more than 300 miles away from the stockpiles in the stockpile shapefile. (The sample stockpiles are all located in Wisconsin, so an address in Wisconsin is a good place to start)
- Make sure there is no extra space after the colon

11. Enter the project name

- Type in the name of the project, try to keep the name less than 100-150 characters
- Make sure there is no extra space after the colon

See Figure 1 below for an example of the input parameter entry.

```
>>> runfile('D:/RMWM_Tools/Scripts/RMWM_Router.py', wdir='D:/RMWM_Tools/Scripts')
Please locate the ToolData folder within the SFS RMWM_Tools folder.
Example: C:\User\RMWM_Tools\ToolData :D:\RMWM_Tools\ToolData

Please locate the material stockpile data path.
A sample dataset is included in the RMWM_Tools\ToolData folder named stockpiles.shp. :D:\RMWM_Tools\ToolData\stockpiles.shp

Please locate the facility data path.
A sample dataset is included in the RMWM_Tools\ToolData folder named facilities.shp. :D:\RMWM_Tools\ToolData\facilities.shp

Please choose the name and location of the output route polyline shapefile.
Example: C:\Users\RMWM_Tools\ToolData\route.shp :D:\RMWM_Tools\ToolData\route.shp

Please locate the map document path.
A template map document is included in the RMWM_Tools\ToolData folder named Template10.2.mxd. :D:\RMWM_Tools\Template10.2.mxd

Please enter the address of your project location
Example: 1415 Engineering Drive, Madison WI, 53706: 1415 Engineering Drive, Madison WI, 53706

Please enter the name of your project: University of Wisconsin Madison|
```

Figure 1. Example RMWM Routing Tool input parameter entries

12. As long as all of the parameters were entered correctly, the script will run and begin to produce results

- The script will take a few minutes to run, be patient

Outputs

The tool produces 4 main outputs:

1. Route directions from project location to the nearest stockpile (Figure 2)
 - Printed in the console

```
Route directions from 1546-1556 Engineering Dr, Madison, WI 53706, USA to W4501 Lime Rd, Eden, WI 53019, USA provided by Google Map Data.

The total driven distance is 77.9 mi and the estimated duration of the trip is 1 hour 24 mins.
Head east on Engineering Dr toward N Randall Ave
1 min (322 ft)
Turn right onto N Randall Ave
1 min (413 ft)
Turn left onto W Dayton St
1 min (0.2 mi)
Turn left onto N Charter St
1 min (413 ft)
Turn right onto W Johnson St
7 mins (2.3 mi)
Turn right onto N Baldwin St
1 min (0.2 mi)
Turn left onto US-151 N/E Washington AveContinue to follow US-151 N
1 hour 9 mins (71.1 mi)
Turn right onto Co Rd V
1 min (0.2 mi)
Co Rd V turns slightly left and becomes County Rd V
1 min (220 ft)
Turn right to stay on County Rd V
1 min (0.3 mi)
Continue onto Co Rd V
4 mins (3.2 mi)
Turn left onto Lime RdDestination will be on the right
1 min (0.1 mi)

Success, polyline route created. Here is some information about your route shapefile and map document:

File path: D:\RMM\Tools\ToolData
File name: route.shp
Shape type: Polyline

Map document path: D:\RMM\Tools\ToolData
Map document file: Route_dir.mxd
```

Figure 2. Example route directions printed in Spyder console

2. Nearest_5_Piles table (Figure 3)
 - Table includes nearest 5 stockpiles to the project, sorted in ascending order by distance
 - Also includes facility contact information

| NEAR_RANK | FROM_X | FROM_Y | NEAR_X | NEAR_Y | TYPE | QUANTITY | UNITS | FAC_NAME |
|-----------|------------|-----------|------------|-----------|--------------|----------|-------------|---|
| 1 | -89.327441 | 43.801174 | -88.381886 | 43.703608 | Foundry Sand | 12000 | Cubic Yards | Eden Stone Co. |
| 2 | -89.327441 | 43.801174 | -88.444527 | 44.338477 | RAP | 200 | Tons | Murphy Concrete and Construction Mackville Aggregate Quarry |
| 3 | -89.327441 | 43.801174 | -88.44421 | 44.338694 | RCA | 750 | Tons | Murphy Concrete and Construction Mackville Aggregate Quarry |
| 4 | -89.327441 | 43.801174 | -88.443991 | 44.339018 | Foundry Sand | 15000 | Cubic Yards | Murphy Concrete and Construction Mackville Aggregate Quarry |
| 5 | -89.327441 | 43.801174 | -90.143481 | 44.655734 | Foundry Sand | 2000 | Tons | Panther Creek Sand Inc. |

Figure 3. Example nearest_5_piles table

3. Map Document (Figure 4)
 - Route_dir.mxd will be located in ToolData folder

- Includes all layers (stockpiles, facilities, project location, nearest route, nearest_5_piles table)

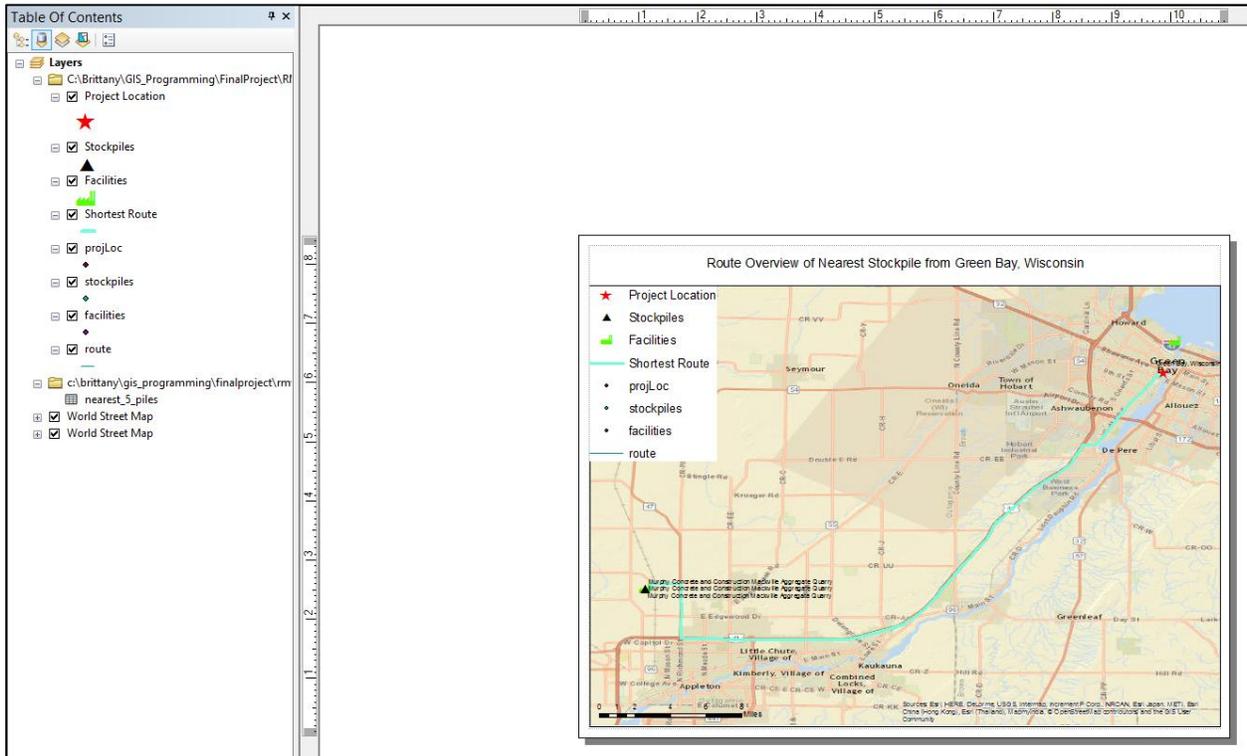


Figure 4. Example ArcMap Document generated from RMWM Routing Tool

4. PDF Document (Figure 5)

- Route_dir.pdf located in ToolData folder
- Route overview map zoomed into the route (including 20% buffer) including legend, title, and scale
- Ready to print

Directions to Nearest Stockpile from Daisy Lane

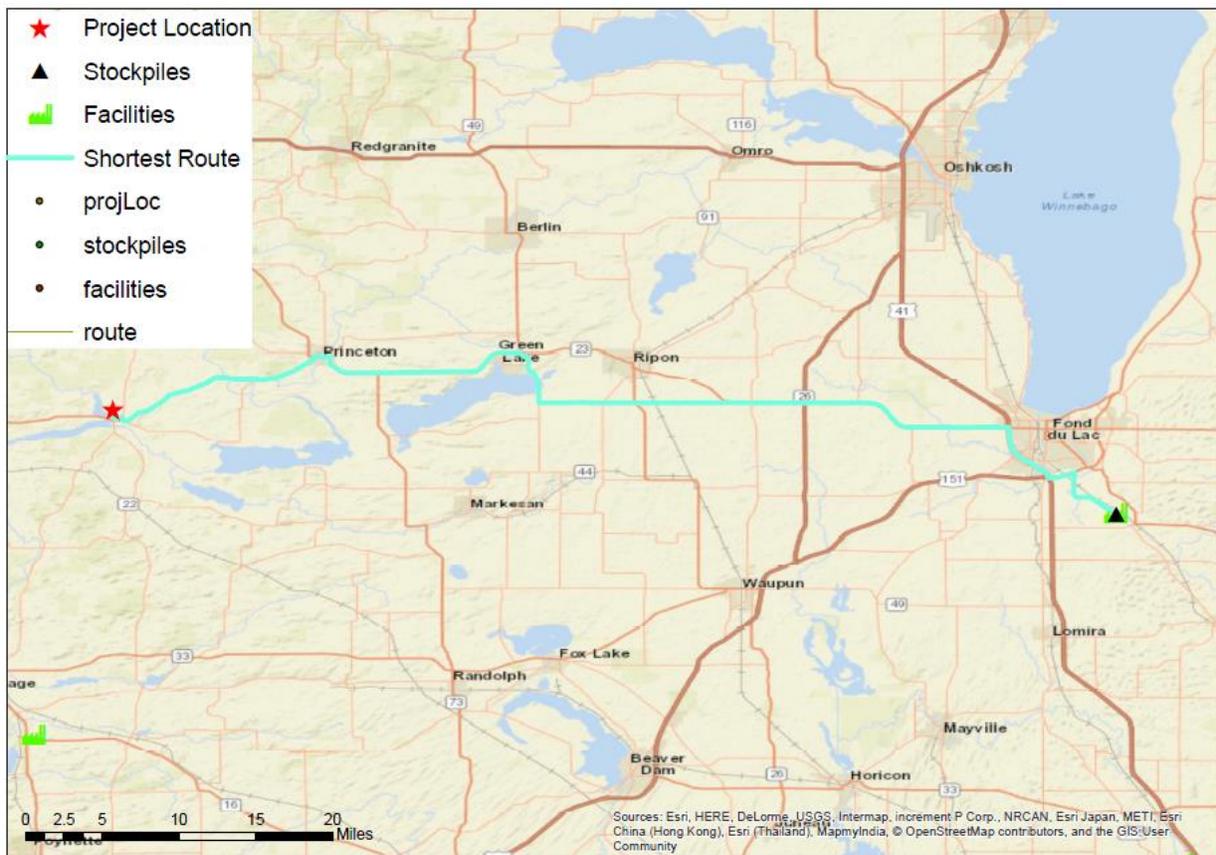


Figure 5. Example PDF map generated using the RMWM Routing Tool

Troubleshooting

- Make sure the appropriate client libraries are installed (see Install Instructions in Doc folder)
- Delete all files in ToolData folder except the original files before you run the tool again. The original files are shown in Figure 6.

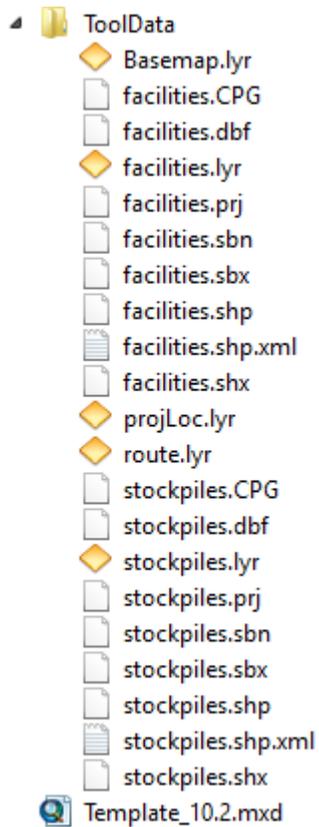


Figure 6. Original ToolData files

- Make sure you have an ArcGIS Advanced Desktop License
- Google is your friend

PYTHON CODE

Name: Recycled Materials Web Map Desktop Routing Tool

Description:

This script asks the user for a project location and name and uses GoogleMaps routing capabilities to identify the 5 nearest material stockpiles and the respective facility contact information. Then, Google Map step-by-step directions are generated for the project location to the nearest stockpile. Finally, a PDF document and MXD document are created including the route overview and the layer files. Compatible with ArcGIS 10.2 and 10.3.

Requirements:

1. Advanced ArcGIS Desktop License
2. Install googlemaps client library
3. Connect to arcpy and googlemaps via PYTHONPATH manager ****detailed installation instruction provided in the Doc folder****
4. Choose template map document included to generate MXD & PDF
5. Project location should be within 300 miles of the closest stockpile

Author: Brittany Shake, bshake@crimson.ua.edu

Latest Update: 4/27/2016

```

# https://github.com/googlemaps/google-maps-services-python

import googlemaps

import os

import arcpy

import re

# Set workspace and locate input stockpile shapefile

arcpy.CheckExtension("Spatial")

arcpy.CheckOutExtension("Spatial")

workspace = raw_input("Please locate the ToolData folder within the SFS RMWM_Tools
                        folder.\nExample: C:\User\RMWM_Tools\ToolData :")

arcpy.env.workspace = workspace

arcpy.env.overwriteOutput = True

stockPath = raw_input("\nPlease locate the material stockpile data path.\nA sample dataset is
                        included in the RMWM_Tools\ToolData folder named stockpiles.shp. :")

stockSF = os.path.basename(stockPath)

facPath = raw_input("\nPlease locate the facility data path.\nA sample dataset is included in the
                        RMWM_Tools\ToolData folder named facilities.shp. :")

facSF = os.path.basename(facPath)

routePath = raw_input("\nPlease choose the name and location of the output route polyline
                        shapefile.\nExample: C:\Users\RMWM_Tools\ToolData\route.shp :")

routeSF = os.path.basename(routePath)

if arcpy.Exists(routePath) == False:

```

```

    arcpy.CreateFeatureclass_management(workspace, routeSF, 'Polyline')

mxdPath = raw_input("\nPlease locate the template map document path included in the

    RMWM_Tools\ToolData folder named Template10.2.mxd. :")

mxd = os.path.basename(mxdPath)

# Use GoogleMaps to retrieve coordinates of user-entered address

# http://py-googlemaps.sourceforge.net/

userAddress = raw_input("\nPlease enter the address of your project location\n"

    "Example: 1415 Engineering Drive, Madison WI, 53706: ")

projectName = raw_input("\nPlease enter the name of your project: ")

gmaps = googlemaps.Client(key='XXXXXXXXXXXXXXXXXXXXXXXXXXXX')

gcodeResult = gmaps.geocode(userAddress)

locInfo = gcodeResult[0]['geometry']

lat = locInfo['location']['lat']

lng = locInfo['location']['lng']

# Add user's location to map

userPath = arcpy.CreateUniqueName("projLoc.shp")

userPoint = os.path.basename(userPath)

spat_ref = arcpy.Describe(stockPath).spatialReference

if arcpy.Exists(userPoint) == False:

    arcpy.CreateFeatureclass_management(workspace, userPoint, 'Point', "", "",

        "", spat_ref)

```

```

lstFields = arcpy.ListFields(userPoint)

if lstFields != "proj_Name":

    arcpy.AddField_management(userPoint, "proj_Name", "TEXT")

cursor = arcpy.da.InsertCursor(userPoint,["SHAPE@XY"])

lngLat = (lng, lat)

cursor.insertRow([lngLat])

cur = arcpy.UpdateCursor(userPoint)

for row in cur:

    row.proj_Name = projectName

    cur.updateRow(row)

del cursor

del row

del cur

# Calculate geodesic distance from project to nearest 5 stockpiles

# Use Generate Near Table tool, need ArcGIS Desktop Advanced License

arcpy.CheckProduct("arcinfo")

# required parameters

in_features = userPoint

near_features = stockSF

out_table = "nearest_5_piles"

# optional parameters

search_radius = "300 Miles"

```

```

location = "LOCATION"

angle = "NO_ANGLE"

closest = "ALL"

closest_count = 5

method = "GEODESIC" # only works in Arc 10.3

# execute the function

arcpy.GenerateNearTable_analysis(in_features, near_features, out_table,

                                search_radius, location, angle, closest,

                                closest_count)

# Join facility information to stockpile table

# Set the local parameters

in_FC = stockSF

in_Field = "Fac_Name"

join_FC = facSF

join_Field = "Name"

field_List = ["Name", "Phone", "Email", "ContFirst", "ContLast", "Hours", "FacType"]

# execute the function

arcpy.JoinField_management (in_FC, in_Field, join_FC, join_Field, field_List)

# Join stockpile feature class to nearest_5_piles table

# Code modified from code sample on ArcGIS help

# Set the local parameters

```

```

inTable = out_table

inField = "NEAR_FID"

joinFC = stockSF

joinField = "FID"

fieldList = ["Type", "Quantity", "Units", "Fac_Name", "Phone", "Email", "ContFirst",
            "ContLast", "Hours", "FacType"]

# execute the function

arcpy.JoinField_management (inTable, inField, joinFC, joinField, fieldList)

# Use Near tool to find the closest stockpile

# Nearest distance, XY, and FID is added to the input user location point shp

# modified code sample from ArcGIS help

# set local variables

in_feat = userPoint

near_feat = stockSF

search_rad = "300 Miles"

loc = "LOCATION"

ang = "NO_ANGLE"

meth = "GEODESIC" # only works in Arc 10.3

# execute the function

arcpy.Near_analysis(in_feat, near_feat, search_rad, loc, ang)

# Join nearest_5_piles table to userPoint

```

```

inFeat = userPoint

inFld = "NEAR_FID"

joinTab = out_table

joinFld = "NEAR_FID"

fldList = ["Type", "Quantity", "Units", "Fac_Name", "Phone", "Email", "ContFirst", "ContLast",
           "Hours", "FacType"]

# execute the function

arcpy.JoinField_management (inFeat, inFld, joinTab, joinFld, fldList)

# Retrieve nearest stockpile coordinates from userPoint and save as variables

scurs = arcpy.da.SearchCursor(userPoint, ["NEAR_X", "NEAR_Y"])

for record in scurs:

    nearX = record[0]

    nearY = record[1]

del record

del scurs

# Use GoogleMaps to generate directions to the closest stockpile

# Use NEAR coordinates in the userPoint shapefile

# HTML stripping code modified from http://stackoverflow.com/questions/753052/strip-html-
# from-strings-in-python post

start = lat,lng

end = nearY,nearX

```

```

dirs = gmaps.directions(start, end, mode="driving")

direct = dirs[0]['legs']

startAdd = direct[0]['start_address']
endAdd = direct[0]['end_address']
totDist = direct[0]['distance']['text']
totTime = direct[0]['duration']['text']

routeHeader = "\nRoute directions from {0} to {1} provided by Google Map Data.\n\nThe total
                driven distance is {2} and the estimated duration of the trip is {3}.".format(startAdd,
                endAdd, totDist, totTime)

print routeHeader

rtDirList = []

route = direct[0]['steps']

for step in route:

    html = step['html_instructions']

    html_strip = re.sub('<[^<]+?>', "", html)

    print html_strip

    print str(step['duration']['text']) + ' ' + '(' + str(step['distance']['text']) + ')'

    del step

# Decode polyline string from googlemaps result into X and Y coordinates that
    represents the overview route

# Code found at https://gist.github.com/signed0/2031157

point_str = dirs[0]["overview_polyline"]["points"]

```

```
coord_chunks = [[]]

for char in point_str:

    value = ord(char) - 63

    split_after = not (value & 0x20)

    value &= 0x1F

    coord_chunks[-1].append(value)

    if split_after:

        coord_chunks.append([])
```

```
del coord_chunks[-1]
```

```
coords = []
```

```
for coord_chunk in coord_chunks:
```

```
    coord = 0
```

```
    for i, chunk in enumerate(coord_chunk):
```

```
        coord |= chunk << (i * 5)
```

```
    if coord & 0x1:
```

```
        coord = ~coord #invert
```

```
    coord >>= 1
```

```
    coord /= 100000.0
```

```
    coords.append(coord)
```

```
points = []
```

```
prev_x = 0
```

```

prev_y = 0
for i in xrange(0, len(coords) - 1, 2):
    if coords[i] == 0 and coords[i + 1] == 0:
        continue
    prev_x += coords[i + 1]
    prev_y += coords[i]
    points.append((round(prev_x, 6), round(prev_y, 6)))

listSize = len(points)

# Add these coordinates as new point feature
# Create route vertices shapefile
rtPointPath = arcpy.CreateUniqueName("routePoints.shp")
rtPointSF = os.path.basename(rtPointPath)
if arcpy.Exists(rtPointPath) == False:
    arcpy.CreateFeatureclass_management(workspace, rtPointSF, 'Point', spatial_reference =
        spat_ref)

icurs = arcpy.da.InsertCursor(rtPointSF, ["SHAPE@XY"])
point = arcpy.Point()
# loop through nested list and use cursor insert row to add records to the point shapefile
x = 0
while x < listSize:

```

```

point = [(float(points[x][0]),float(points[x][1]))]

icurs.insertRow(point)

x += 1

del icurs

# Convert the route points into a route polyline feature using Points to Line Tool

inPoints = rtPointSF

outLine = routeSF

arcpy.PointsToLine_management(inPoints, outLine)

shapeDesc = arcpy.Describe(routeSF)

print "\nSuccess, polyline route created. Here is some information about your route shapefile and
      map document: \n"

print "File path: " + shapeDesc.path

print "File name: " + shapeDesc.file

print "Shape type: " + shapeDesc.shapeType

# Create map document object and add layers/symbology to map

mapDoc = arcpy.mapping.MapDocument(mxdPath)

dfList = arcpy.mapping.ListDataFrames(mapDoc)

routeDF = arcpy.mapping.ListDataFrames(mapDoc)[0]

lyr1 = arcpy.mapping.Layer(userPath)

```

```

addLyr1 = arcpy.mapping.AddLayer(routeDF, lyr1, "BOTTOM")
sym1 = workspace+"\\\\"+"projLoc.lyr"
arcpy.ApplySymbologyFromLayer_management(lyr1, sym1)
lyr2 = arcpy.mapping.Layer(stockPath)
addLyr2 = arcpy.mapping.AddLayer(routeDF, lyr2, "BOTTOM")
sym2 = workspace+"\\\\"+"stockpiles.lyr"
arcpy.ApplySymbologyFromLayer_management(lyr2, sym2)
lyr3 = arcpy.mapping.Layer(facPath)
addLyr3 = arcpy.mapping.AddLayer(routeDF, lyr3, "BOTTOM")
sym3 = workspace+"\\\\"+"facilities.lyr"
arcpy.ApplySymbologyFromLayer_management(lyr3, sym3)
lyr4 = arcpy.mapping.Layer(routePath)
addLyr4 = arcpy.mapping.AddLayer(routeDF, lyr4, "BOTTOM")
sym4 = workspace+"\\\\"+"route.lyr"
arcpy.ApplySymbologyFromLayer_management(lyr4, sym4)
lyr5 = arcpy.mapping.Layer(workspace+"\\\\"+"Basemap.lyr")
addLyr5 = arcpy.mapping.AddLayer(routeDF, lyr5, "BOTTOM")

# Remove feature classes
arcpy.mapping.RemoveLayer(routeDF, lyr1)
arcpy.mapping.RemoveLayer(routeDF, lyr2)
arcpy.mapping.RemoveLayer(routeDF, lyr3)
arcpy.mapping.RemoveLayer(routeDF, lyr4)

```

```

arcpy.mapping.RemoveLayer(routeDF, lyr5)

# Zoom to extent of route layer in route data frame

lyrZoom = arcpy.mapping.ListLayers(mapDoc, 'route*', routeDF)[0]
ext = lyrZoom.getExtent()

routeDF.extent = ext

routeDF.scale = routeDF.scale * 1.2

# Add route directions and title to text elements in a new data frame

mapDoc.title = "Route Overview of Nearest Stockpile from" + " " + projectName
titElm = arcpy.mapping.ListLayoutElements(mapDoc, "TEXT_ELEMENT", "TitleText")[0]
titElm.text = "Route Overview of Nearest Stockpile from" + " " + projectName

# Refresh

arcpy.RefreshTOC()

arcpy.RefreshActiveView()

# Save map document and export to PDF

mapDocSave = workspace + "\\\" + "Route_dir.mxd"

mapDoc.saveACopy(mapDocSave)

arcpy.mapping.ExportToPDF(mapDoc, workspace+'\\'+'Route_Dir.pdf')

mapDesc = arcpy.Describe(mapDocSave)

print "\nMap document path: " + mapDesc.path

```

```
print "Map document file: " + mapDesc.file
```

```
# Cleanup
```

```
del mapDoc
```

```
del dfList, routeDF
```

```
del lyr1, lyr2, lyr3, lyr4, lyr5
```

```
del addLyr1, addLyr2, addLyr3, addLyr4, addLyr5
```

```
del sym1, sym2, sym3, sym4
```

```
del titElm
```

```
del lyrZoom
```

```
arcpy.CheckInExtension("Spatial")
```