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Modeling the problem of assigning Virginia's localities to DCR's Regional Offices

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“Modeling the problem of assigning Virginia’s localities to DCR’s Regional Offices.”

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Mathematics with a concentration in Applied Mathematics at Virginia Commonwealth University.

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Abstract

MODELING THE PROBLEM OF ASSIGNING VIRGINIA'S LOCALITIES TO DCR'S REGIONAL OFFICES.

By SUDHARSHANA SRINIVASAN, B.E.

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Virginia's Department of Conservation and Recreation (DCR) assigns all of Virginia localities to Regional Offices to help conserve the natural resources in a certain region. In this paper, we present a mathematical model for optimizing such assignments by minimizing the travel time and cost of these assignments. With the growing increase in fuel costs and tighter budgets, our solution finds alternate assignments that will help cut costs by 14% annually. We have used integer programming techniques to find optimal assignments which satisfy requirements, respect limitations and minimize cost. Several plans are suggested, some keeping soil and water conservation districts together and some without.

INTRODUCTION

Modeling the problem of assigning Virginia's localities to DCR's Regional Offices.

Need for Study

The Department of Conservation and Recreation (DCR) helps in coordinating programs for protecting the environment of the Commonwealth of Virginia and its localities. Water from rains and snowmelt carries contaminants when it flows through the land. The sources of contamination are varied ranging from oils and hazardous chemicals to toxins and disease causing agents. Such pollution of water is called non-point source (NPS) pollution. Most of the programs, directed by DCR, work towards controlling and eliminating NPS pollution. In addition to the NPS programs, DCR is responsible for the administrative, technical and financial support of soil and water conservation districts (SWCDs) and conservation district coordinators (CDCs).

Established in the 1930's, the SWCDs help in nurturing the environment within the defined boundaries of a district. They help with flood prevention and sewage and water disposal for all localities that fall under the specified district. Over a period of 80 years, forty-seven districts have been identified to serve Virginia's localities.

The CDCs form an intermediary between the Commonwealth and the districts. They help coordinate several programs and activities, interacting with the district directors and employees, and overseeing financial and personnel issues. In addition, their

responsibilities include overseeing district elections, bridging between state and federal agencies, managing budgeting issues, and deciding on district boundary realignments.

Also, DCR has identified program areas that include erosion and sediment (ES) control, storm water management, nutrient management, and watershed field coordination (WFC). The department staff ensures that they service all Virginia localities that have problems in one or more of these program areas. Eight regional field offices have been identified and established, based on geographical divisions and potential work sites, to assist and support the SWCDs in servicing the localities. Some have the primary responsibilities of technical and administrative support, while others develop and execute sound resource management programs.

Each program area is unique in its own right with regard to nature of work and has specific requirements. Nutrient Management involves visiting producers to help them attain permits for farms, and to ensure that the crops, livestock, produce or poultry are all within the regulated norms and standards. Soil samples are collected and sent to labs at Virginia Polytechnic Institute and State University for testing. The number of trips depends on the size of the farms. Storm Water management and ES help in controlling and preventing damages caused by storm water run-off and contamination of soil and aquatic resources. These projects range over a period of 2 to 20 years depending upon the scope of the project. The work includes meeting with clients and discussions with other regional officers, getting an approval for the plan and frequent site visits. WFC works with local government and Non-Governmental Organizations (NGOs) to develop grants and proposals.

There has been a tremendous increase in work load and hence the workforce for DCR, since the late 1980's. This has given rise to a need for efficient distribution of available human resource within the regional offices, so that demands can be fulfilled. The original offices were located based on close proximity and commuting distance of the homes of 6 CDCs. The configuration of regional office service areas has evolved over time. The area of highest importance is WFC. Watersheds are areas that drain into a water body. Earlier assignments of localities to regional offices were made based on the amount of watershed field activities. Most recently, localities have demands in other program areas and the agency has changed focus from watershed based service areas to locality/district based service areas. Much time has been spent over the years trying to accommodate the workload, program areas and district support. Most of the work involves site visits, requiring travel between work sites and regional offices. This project is an attempt to conduct a cost study to evaluate efficient assignments of localities to regional offices in order to reduce time and money spent on travel.

Overview of Paper

The goal of this work is to generate an efficient assignment of Virginia's localities to regional offices. DCR, as with other government entities, is experiencing decreasing budgets and increasing demands. The staff and programs they serve continue to grow, and much of the work time is spent on travel between offices and localities. Travel costs form a major chunk of the total cost incurred by the Division. DCR wants to evaluate the cost effectiveness of the current assignment and believes that reassigning some of the existing

localities may result in tangible annual cost savings. We have developed analytical models based on our understanding of the problem situation. We used mathematical programming tools to implement our models and find solutions that meet the demands of the localities, respect the resource limitations of the regional offices, and reduce the costs of assignments. We have suggested several possible solutions, provided an analysis of these solutions, and given cost comparisons to enable better understanding of the solutions.

BACKGROUND

Problem Domain

Management of Natural Resources has always been a priority. With the steady increase in population, protecting our scarce resources from depletion has become a priority. Enhancements in technology have resulted in the development of a complex system or framework to control and manage the available resources. Human minds crave perfection and strive for betterment! Therefore, generating an efficient system for the management of natural resources has provided food for thought for several researchers around the globe. Operations Research (OR) emerged as a means to find optimal solutions for the several problems that arose within this huge domain.

Over the last 40 years, OR has helped tackle potential problems in areas such as agriculture, forestry, fisheries, soil and water conservation, and mining. Most of these areas are subject to government regulations. This adds complexities within the underlying decision process. OR serves as a support system which enables us to make logical decisions to obtain an efficient allocation of available resources and to decrease the harmful impacts on the environment.

Weintraub and Romero (2006) look at several problems in agriculture and forestry, and provide a comparison of the OR models applied to solve these problems. Forests provide a vast set of natural resources and house a plethora of flora and fauna. Some of the problems include harvesting decisions (short-term, medium range, long-term), location of harvesting plants and machinery, transportation of timber and other products, and laying

roads or trails. Operations research methods have been widely used for planning and managing complex systems in forestry. Mostly heuristic and stochastic models are used as the data set is huge and most methods use forecasting schemes to predict solutions. There have been many models developed since 1960. Several issues such as soil conservation, wildlife preservation, rainfalls, and scenic beauty add complexities to these models. Kirby et al. (1986) used mixed integer models for integrating harvesting decisions with road building. In forest management, habitat patches are defined for wildlife. No harvesting is done on such patches, there by conserving wildlife. Barahona et al. (1992) used LP formulation with column generation to ensure that no two adjacent units or areas within the plantation region can be harvested in the same period (adjacency problem). The resulting stable set problem was solved using a cutting plane approach. They tested their models using data from pine plantations in Chile. Fletcher et al. (1999) discussed the environmental concerns of plantations in the US and developed a model which they call the eco-esystem planning express model (Ep(x) model). They use Geographic Information Systems (GIS) and databases to identify special habitats and vegetation sets and to generate the decision variable set, which is then fed into their LP model. The decision variable set represents decisions on the size and location of plantations. Their model accounted for a 120 year, 12 period management plan, which resulted in a $29 million increase in net revenue. Cea and Jofré (2000) presented a model to be used by pulp plants and sawmills. Timber from the plantations is transported to the mills and other industrial plants around the plantations. Their model combines harvesting decisions as well as decisions to build, expand or close the industrial complexes. They discuss a two-level

model: a strategic model that helps in deciding harvesting patterns, and a tactical model that generates what roads have to be built to connect all the sites (plantations and industrial). They use mixed integer programming with an MIP solver for the strategic model and a version of the Simulated Annealing algorithm for the tactical model. They integrate the results of the models using cluster analysis (K means algorithm). In recent years, there has been a lot of work in the department of forestry. Sowlati et al. (2008) have done work in optimization, efficiency, and productivity assessment in forestry, biomass, and bio-energy.

In agriculture, Heady (1954) is considered a pioneer in generating LP models to optimize farm-level decision making. In his paper he focuses on the logic of LP models, rather than the mathematics behind it. Following his work, many models were developed which helped decide cropping patterns, sizes of fixed farm equipment, and economic impact of agricultural policies. Research indicates that most farmers like to work a compromise between several objectives (getting a profitable harvest, using minimum area, providing area for farm equipment, and minimizing costs), rather than to achieve a single target. This resulted in multiple objective programming initiated in 1984 by Romero and Rehman. They discuss a goal programming approach to a multiple objective model for deciding on dietary blends for livestock. In their model, they think of deriving nutrition as achieving targets (goals) and analyze multiple objectives. Their results were used to decide live stock ration for dairy cows in Andalusia, Spain. The earlier models either based decisions only on cost of diet or had strict nutritional requirements. There have also been several other models in the literature which help to find efficient feeding schemes for

livestock. Rae (1994) developed binary programming models which were multi-period and also extended the size of the problem from farm-level to regional-level.

Water resource management also serves as a compendium of problems. Some of the problems found in the literature are deciding on water supply and storage options, and selecting water restoration projects and water management policies for a city or region. Eder et al. (1997) describe methods to decide locations for hydro-electric power plants on the Danube River in Austria. They use a multi-criteria Q- Analysis technique to rank and/or prioritize several criteria that help in making decisions, while considering political, economic and sociological factors. The analysis results in an evaluation matrix which suggests several alternatives. This information is used by an mixed integer programming model to generate locations of the energy plants. Al-Rashdan et al. (1999) discuss methods to prioritize projects designed to improve the environmental quality for Jordan. They use a software based method called PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluation) for their study and sensitivity analysis. Due to a large data set, they required seven iterations of their software before they obtained an optimal solution. Their solution was a starting point in reviewing water policies in Jordan. Flug et al. (2000) present a model to decide on water flow options for the Glen Canyon Dam in Colorado. They have to choose from 9 flow options using 7 water sources and 29 criteria. Their results are under study by the Adaptive Management Program under the Glen Canyon Protection Act. Optimizing water supply augmentation and demand management policies for the City of Cape town are discussed by Joubert et al. (2003). They use additive value function models and multi-criteria decision analysis to rank policies and present a possible

set of projects. Another area within this domain, with scope for improvement, is wastewater management. The wastewater generated in urban areas is one of the main sources of water pollution. Cunha et al. (2009) present a mixed integer network programming model for regional wastewater systems planning. The model is aimed at determining the best possible layout of sewer networks and location of treatment plants.

Similar Problems

Advancements in technology have helped us find new methods to be able to model real world problems and find solutions to these problems. Operations Research is a branch of applied mathematics, which helps us find optimal solutions to several practical problems in various fields such as engineering, transportation, energy, telecommunications, and manufacturing. Some of the classical problems in these areas are planning, scheduling, routing, assigning, location and layout design.

As addressed by Geoffrion and Powers (1980) in their paper, the most frequently asked question by companies that offer goods and/or services is "How many warehouses should we have?" Facility location is one of the classical optimization problems, which concerns placing of facilities to cater to the needs of customers or clients within a defined neighborhood by minimizing one or more of the following travel times, travel costs, response times, and distance travelled. Another version of this problem is the capacitated facility location problem, which restricts how much service is available for use at a facility. There are many operations research methods and tools that have been used to solve facility

location problems in the literature. The goal for each of these methods is to decide which customers are served by which facility such that the "cost" is minimized.

In 1984, Fok et al. developed a single-period annual cost model to help Lockheed Missiles and Space Company's building facilities in Sunnyvale, California, to relocate their stationary storage facility. The inventory was originally located about 10 miles away from the main user region, and the cost of deliveries of the stationary supplies was significantly increasing as a result of population growth and changes in traffic patterns along delivery routes. The model developed is a fairly straightforward mixed integer programming model which helped determine an optimal location of a central stationary distribution facility such that total operating and transportation cost was minimized. Their findings suggested that deliveries had to be made directly to users, as the cost for storage in the main building complex was higher than the cost of transportation. Sometimes our analytical approach might not give new results, but provide a certificate of optimality for an existing solution.

Shri. Shakti LPG Ltd. (SSPLG) is an agency that imports and markets propane to both industrial and domestic customers in South India. Sankaran and Raghavan (1997) proposed a single period binary integer programming model to help locate propane bottling stations in dealer towns such that annual costs can be minimized for a certain target year. The cost is basically broken down into several components such as operational costs for the bottling stations and the cost for satisfying the demands at the dealer towns. This includes cost of transporting LPG from ports to bottling stations, cost of bottling, cost of loading and unloading trucks, and cost of transporting gas cylinders (filled or empty)

between bottling plants and dealer towns. Their model was a variation of the Capacitated Facility Location Problem. Since it was hazardous to transport filled cylinders over long distances, they used the Archimedean spiral notion (i.e.to find radius of a moving object from a fixed point) to specify boundaries for each possible site. Their estimates claim that the new configuration suggested by them would result in an annual cost savings of $1 million for the SSPLG.

In 1999, Antunes proposed a facility location analysis to help manage solid waste in the Portuguese Centro region. In his proposal he defined a network of sanitation landfills where Municipal Solid Waste (MSW) can be disposed. His study also details the management process and the time between each stage so that an efficient solution can be found. The problem had to be tackled both at the local as well as regional level. The model has a multi-objective nature: maximize distance between sanitation landfills and urban centers, and minimize distance between sanitation landfills and producers of MSW. Due to the large numbers of sites (78 centers, 18 sanitary landfill locations, 86 transfer station locations) a heuristic approach was used. A mixed-integer network optimization model was developed. The Centro Region Coordination Agency (CCRC) was provided with a solution of 8 landfills and 8 transfer stations which they implemented.

Chiang et al. (2002) consider the problem of workflow interference using a variation of the quadratic assignment problem known as the “Quartic assignment problem”. They look at pairs of pairs of facilities and the workflow interference between them (if it exists). They incorporate four binary variables to denote relationships between two pairs of facilities. They solve their quartic model using extensive branch and bound

algorithm. For the sake of comparison and analysis, they also use tabu search techniques. Their heuristic solution actually works well (almost 153 solutions out of 166 were optimal solutions), even for larger problem sizes and also the CPU times were efficient.

Our problem is a resource allocation problem, modeled using mixed integer programming. We would like to make an assignment of localities to regional offices such that the resources (work force or man-hours) available at each regional office are allocated optimally and demands (operation hours required at each locality) are satisfied while minimizing the costs (travel time and mileage costs).

STUDY

Objective

Each regional office has a fixed number of man-hours available per program area. Each locality requires certain number of trips and man-hours per program area. We have to ensure that the assignment not only respects the human resource availability of the office, but also meets the demands of the locality. Each locality is also a part of a SWCD. Since the SWCD are the most important customers of Division of Soil and Water Conservation, DCR, we also considered a case where all localities in the same district are served by the same regional office. DCR assigns each locality to a regional office by considering the proximity of the locality from the office. Due to the nature of work, most time is spent on travelling between site and office.

Mr. J. Michael Foreman, Deputy Director, Division of Soil and Water Conservation, DCR and Mr. Kelly S. Vanover, Regional Manager, Warrenton Office, DCR with the help of Regional Managers and other staff conducted an extensive study to initiate an analysis of the current service boundary of regional offices, i.e. the localities and districts that they served. The purpose of the Regional Office Service Area study was to identify possible changes to the regional office boundaries that might result in considerable cost savings and enable the division to provide efficient and effective service. They wanted to find if there were any compelling benefits that would justify making a change to any regional office boundary. They also wanted to analyze the current configuration and see if

there was any scope for improvement. With the growing increase in fuel costs and tighter budgets, our solution will help cut costs by finding alternate assignments.

Synopsis

On May 5th 2008, they approached Dr. Jill Hardin and discussed methods to model the problem using analytical tools and to optimize the current configuration. They were presented with a prospectus describing several abstract models that can be used to represent their problem. Understanding the problem domain and identifying data required was a crucial part of the analysis. The study was conducted in an inclusive and transparent manner, with regular updates to and communication with the client. Any questions and concerns regarding the problem were addressed to the clients, who promptly responded and enabled us to further our study.

As part of the study, we visited the DCR regional office at Warrenton, Virginia to get a perspective on how DCR functions and how different programs are implemented, and to gain some background information about the existing situation. We met with the staff to discuss their individual program areas and requirements. They also talked about demands, expectations and current workload. We got to see how and where our solutions would be implemented and the impact of the changes that we might suggest. This was especially beneficial for us. The final stages of the study included analyzing our solutions, checking for accuracy and presenting our solutions to our clients in a meeting held on 15th December 2008. Regional managers from each office attended the meeting. The presentation was followed by a discussion where the alternatives were considered.

RESEARCH METHODS

Problem Description

DCR employees currently spend most of their time on travel to and from worksites. DCR assignments are driven by travel costs, which have two major components:

a) Mileage component: This takes into account the total number of miles travelled in the several trips made between the site and office, multiplied by the State Mileage rate.

b) Travel Time component: This takes into account the total time spent on travel in the several trips made between the site and office, multiplied by the salary or travel allowance.

We were asked to find an assignment of localities to regional offices that minimized the COMBINED COST which is calculated as shown below:

TOTAL COST = ANNUAL MILEAGE COST + TRAVEL TIME COST

Annual Mileage Cost = D * T * S

Annual Travel Time Cost = TT * T * Sa

Where, D - Distance in miles between locality and office

T – Annual number of trips required between locality and office

S – State Mileage rate

TT- Travel time in hours between locality and office

Sa – Salary component

We used weights, alpha and beta, for the mileage and travel time component respectively. We also varied the weights to analyze how these cost components affected the assignments. Alpha and Beta contributed towards a total cost factor of 100%. The values for alpha and beta were assigned as follows:

Value for Alpha	Value for Beta	Description
20%	80%	Travel time component weighed greater than Mileage component
50%	50%	Both Mileage and Travel time components were equally weighed
80%	20%	Mileage component weighed greater than Travel time component

Table 1: Selecting values for cost components: alpha and beta

We are also required to satisfy the following restrictions:

- Each Locality is assigned to exactly one Regional Office
- The total annual hours required by a locality per Program Area (onsite, at office and on travel) does not exceed the total annual hours available at Regional Office for that Program Area.

Regional offices and SWCDs are independent entities, but work in collaboration to serve the localities. Each SWCD has a set of localities that it caters to. Virginia has 47 SWCDs that cover almost all of Virginia's counties. Assigning all localities belonging to the same SWCD to the same regional office was intuitive. We were also willing to

consider splitting up of localities belonging to the same SWCD to evaluate the cost and analyze savings that may occur.

Data Collection

Data collection and analysis is an integral part of optimization. A model is sound only when the data used to solve the model is accurate. The data collected was formatted to suit the model.

The model utilized mileage and travel costs to determine the solutions, so we take into account distances and travel times between regional offices and localities. DCR did an extensive job of collecting all the data we required. They used the Rand McNally website (www.RandMcNally.com) to obtain the travel time and travel distance information. All possible localities located within approximately 90 miles from each office were considered. The county seat for each locality was used as the specific point of reference. To ensure that the capacity of the regional office is respected, we collected data (estimates) on the number of annual hours and trips required by a locality in each program area. The hours available per program area at each regional office was determined by the current staffing, i.e. the number of Full Time Employees (FTE) times the hours worked by an average employee in a year per program area in each office. The data collected was based on average annual estimates. Some of the jobs were seasonal or irregular, but we did not account for seasonal data. For example, a beach or a state park requires seasonal trips only for a certain program area. Our model would consider an annual average number of trips

and make an assignment. The human resource for that program area in the regional office is available during off-season. Our model would not account for this resource availability.

The following data was collected by the DCR (Refer APPENDIX A):

- List of Localities – Appendix A.1
- List of Regional Offices – Appendix A.1
- List of Soil Water Conservation Districts – Appendix A.1
- List of Program Areas – Appendix A.2
- # Full time Employees in each Regional Office by Program Area – Appendix A.2
- Travel Time in hours between Regional Office and Locality – Appendix A.3
- Distance in miles between Regional Office and Locality – Appendix A.3
- # Annual Trips required by Program Area for Locality – Appendix A.4
- # Hrs required by Locality per Program Area – Appendix A.4
- Average Annual Salary was considered to be $50,000

Table 2: Data collected

There were several data issues that had to be dealt with while tailoring it to match our needs, such as typographical errors or issues that required us to redesign our model to incorporate the change and to better reflect our problem. For example, DCR only provided the mileage and travel time information for localities located within a 90 mile radius of offices. So to discourage our model from making assignments to offices farther than 90 miles, we assigned a huge cost for such assignments. Sometimes, goodwill, and socio-political reasons required that certain localities be assigned to specific offices. These we referred to as mandatory assignments and forced the model to make these assignments. We had some data issues while assessing the current assignment too. Some localities were assigned to a certain regional office, but were currently serviced by another office. We had to make decisions as to which office it was assigned to currently. Some localities required

trips to be made from two or more offices, so we had to take a total of those trips to decide how much human resource is required by the locality. We also did not have enough information with respect to certain localities (i.e. towns) and so we consulted with DCR and assumed that the town (e.g. Town of Abingdon) would also be assigned with its respective county (Abingdon County). Each time the clients were consulted and the issues were resolved. The process of designing the model and data is iterative and enhancements are made along the way.

Problem Formulation

A. Models considered:

Looking at a problem from different angles helps in a more comprehensive analysis. It also provides us with a basis for comparison of several possible solutions. We looked at our problem from two perspectives:

a) Model to find the best possible assignments of localities to regional office, while keeping SWCD together.

b) Model to find the best possible solution while relaxing the constraint on keeping SWCD together.

This approach was used as it would help us compare alternatives to verify if splitting up of SWCD resulted in considerable annual cost savings.

B. Limitations or Assumptions

Our model was based on several assumptions which were made in consultation with DCR. We were given annual estimates for demand in each locality per program area. Seasonal jobs were not specifically accounted for. This might overlook the availability of resource off-season. We assumed that a full time employee works 40 hours per week for 48 weeks per year. We did not account for any overtime served by the employees. Average salary for an employee was assumed to be a constant of $50,000 annually. The model only considered offices within a 90 mile radius from the localities.

C. Abstract Model

Once the problem is defined, data is collected, and a complete analysis of problem is performed, we have to design a model that would represent the problem. The model and data would then help us to get solution(s) to the problem. We created an abstract mathematical model to represent this problem.

Let the following variables and parameters represent the stated information,

L - The set of Localities

R - The set of Regional Offices

P - The set of Program Areas

J - The set of Soil Water Conservation Districts

D - The set of all localities in districts

N_{lp} - Yearly man hours required by locality l in program area p

NT_{lp} - Yearly trips to locality l in program area p

T_{lr} - Total yearly trips required to locality l

$A_{rp} = FTE_{rp}(48)(40)$ Yearly man hours available at regional office r in program area p

M_{lr} - Mileage to travel from regional office r to locality l

TT_{lr} - Travel time from regional office r to locality l

sal - Average annual salary for employee $50,000/total hours worked (48*40)

smr - state mileage rate

alpha - The weight for mileage cost

beta - The weight for travel time cost

$$x_{lr} = \begin{cases} 1 & \text{if locality l is assigned to office r} \\ 0 & \text{otherwise} \end{cases}$$

$$C_{lr} = (2 * \text{alpha} * M_{lr} * T_{lr} * \text{smr}) + (2 * \text{beta} * TT_{lr} * T_{lr} * \text{sal}) \quad (1)$$

Then,

Objective is to Minimize $\sum_{l}\sum_{r} C_{lr} * x_{lr}$ (2)

Subject to the following constraints:

$$\sum_{r \in R} x_{lr} = 1, \ \forall l \in L \quad (3)$$

$$\sum_{l \in L} x_{lr} * N_{lp} + \sum_{l \in L} 2 * TT_{lr} * x_{lr} * N_{lp} \le A_{rp}, \ \forall r \in R, \ p \in P \quad (4)$$

$x_{d1r} = x_{d2r} \ \forall r \in R, \ d1 \neq d2;$ where $d1, d2 \in L$ and belong to same district $j \in J$ (5)

Equation (1) evaluates the cost parameter. (alpha and beta are weights used for mileage and travel time respectively). Equation (2) is the objective function which tries to minimize the total cost. Equation (3) or the Assignment constraint ensures that each locality is assigned to only one regional office. Equation (4) or the Availability constraint ensures that the requirements or demands are always within the resource available. Equation (5) or the SWCD constraint ensures that when two localities belong to the same district, they are assigned the same regional office. Omitting equation (5) in the model helps in relaxing the requirement for the SWCDs to stay together, and permits splitting of districts.

IMPLEMENTATION

Techniques Used

We used Binary Integer Programming (BIP) to model our problem. The problem has a defined objective which has to be achieved under linear restrictions or constraints, and the solution or decision variables are all binary (i.e. can only take values 0 or 1). Unlike, its linear programming counterpart, which can be solved in polynomial time, the BIP is considered NP-Hard. Advanced algorithms like the branch and bound are used to solve such problems.

Implementing Using GLPK

The GNU Linear Programming Kit (GLPK) is a tool that uses operations research algorithms such as simplex, branch and bound, and primal-dual interior point method to solve mathematical models (both linear and integer programs) and problems.

The model and data file are given as input to the glpsol command, which reads the model file, and generates the objective function and constraints. After generating the model, it gives a description of the method used, the time taken, and the resources utilized to solve the model. It also writes the solution to the output file and declares if the solution is optimal. Our models took between 7 to 8 minutes to solve.

RESULTS AND ANALYSIS

Test Cases

Testing the model and analyzing solutions is an important element of research. When there are large sets of data then it is very important to ensure accuracy of results before delivering it to the clients. We considered three cases:

Case #1: Evaluating costs for existing solution

Case #2: Finding an assignment keeping SWCD together

Case #3: Finding an assignment relaxing SWCD restriction

A comparison of the localities in the current assignments and our possible solutions is included in Appendix C. It is also important to note that the solutions were the same for the different weights on the cost components. This suggested that the two cost components were related and equally contributed in the assignments.

Interpreting Solutions

Case #1: Evaluating costs for existing solution

The current assignment preserves the SWCD by keeping localities under same SWCD in the same Regional Office. However, this assignment was infeasible for our model. Based on the given human resource data, this assignment exceeds availability of man-hours in the following regional offices for the given Program Area:

- Suffolk Office (all Program Areas)
- Richmond Office (Storm Water Mgmt.)
- Tappahannock Office (WFC)

The comparison chart in the following page shows how requirement exceeds availability for each regional office, per program area:

AVAILABILITY

Hours available in Regional office calculated based on # FTE

	ES	Stormwater	Nutmgmt	CDC	WFC
Abingdon	1920	3840	960	1920	1920
Clarksville	1920	1920	1920	1920	960
Christiansburg	1920	3840	1920	1920	960
Richmond	5760	3840	1920	1920	3840
Suffolk	3840	3840	5760	1920	1920
Tappahannock	3840	5760	3840	1920	1920
Warrenton	1920	3840	3840	1920	1920
Staunton	3840	3840	9600	1920	1920

REQUIRMENT

Hours required by localities from Regional office based on Current Assignment

	ES	Stormwater	Nutmgmt	CDC	WFC
Abingdon	914.08	1873.9	274.4	851.24	950.12
Clarksville	1021.96	1660.24	1747.36	1822.68	378.84
Christiansburg	664	1259.02	272.18	700.1	459.06
Richmond	2561.26	4692.62	1868.94	1035.2	559.3
Suffolk	4268.48	4374.68	6005.66	2010.36	2069.84
Tappahannock	2615.14	2840.84	3721.76	1723.6	2129.04
Warrenton	1285.34	1740.22	1123.9	1195.98	1407.78
Staunton	2103.88	3521.4	8242.78	1324.26	512.12

Denotes that requirement is greater than availability

Table 3: Requirement Vs Availability for current assignment

The costs were evaluated for the current assignment using similar weights and evaluation method used by our model.

Case #2: Finding an assignment keeping SWCD together

This assignment ensures that SWCDs stay together and that demand of the localities is met within the availability of regional offices. The cost in comparison to existing assignment is lesser but greater than without SWCD restriction. Comparing with existing assignment, a total of **38 localities** have been reassigned, resulting in a re-assignment of their corresponding SWCDs.

Case #3: Finding an assignment relaxing SWCD restriction

In this assignment, most SWCD stay together, some are just reassigned to a different Regional Office. In total, **39 localities** have been reassigned. This is the best possible cost saving solution among the three solutions analyzed, based on our model, and data collected by DCR. The following table shows the SWCD (and the localities served by it) that stay together but are reassigned to a different office.

SWCD	From Office	To Office
Mountain Castles	Staunton	Christiansburg
Blue Ridge	Clarksville	Christiansburg
Lord Fairfax	Staunton	Warrenton
Appomatox River	Suffolk	Richmond

Table 4: Shift of SWCD between Regional Offices

Some SWCD are split between 2 regional offices

1) Shenandoah Valley

Staunton	Warrenton
Rockingham County	Page County
City of Harrisonburg	

2) Thomas Jefferson

Richmond	Staunton
Fluvanna County	Albermale County
Louisa County	Nelson County
	City of Charlottesville

3) Peaks of Otter

Clarksville	Christiansburg
City of Bedford	Bedford County

4) Peter Francisco

Richmond	Staunton
Cumberland County	Buckingham County

5) Piedmont

Richmond	Clarksville
Nottoway County	Prince Edward County
Amelia County	

6) Culpeper

Warrenton	Staunton
Rappahannock County	Greene County
Culpeper County	Madisson County
Orange County	

7) Tri-County

Richmond	Tappahannock
Stafford County	City of Fredericksburg
	King George County
	Spotsylvania County

8) Chowan Basin

Suffolk	Clarksville
Sussex County	Greensville County
Southhampton County	

9) Hanover Caroline

Richmond	Tappahannock
Hanover County	Caroline County

10) Colonial

Tappahannock	Richmond
York County	New Kent County
	Charles City County
	James City County
	City of Williamsburg

Table 5: Splitting of SWCD between Regional Offices

For example, the Hanover Caroline SWCD consists of two localities, namely, Hanover County and Caroline County. This is split between Richmond and Tappahannock regional offices.

It is important to see how these assignments reflect in costs. A cost comparison was performed to enable us to look at how much cost savings the assignments would provide as compared to the existing assignment. We evaluated total travel time cost, total mileage cost and a total of the two cost factors.

	Current Assignment	Keeping SWCD	Relaxing SWCD	Cost saving keeping SWCD	Cost saving relaxing SWCD
Total Travel Time cost	$366,562.50	$332,451.50	$312,654.70	$34,111.00	$53,907.80
Total Mileage Cost	$383,366.90	$350,133.10	$326,293.10	$33,233.80	$57,073.80
Total Cost	$749,928.90	$682,584.30	$638,947.80	$67,344.60	$110,981.10

Figure 1: Comparing costs for solutions

The above figure indicates that the best possible assignment in terms of cost is when we do not consider the soil and water conservation districts. This can be attributed to the fact that sometimes, localities that are not necessarily in close proximity might still be assigned to the same district. When we do not have the restriction on keeping districts together, the model only picks localities based on mileage and travel time information. It should also be noted that, this model still keeps 34 districts together. Also, both solutions produced by the model are cost effective when compared to the existing assignment. Refer Appendix C for a detailed cost comparison chart with respect to each regional office.

Presenting Solutions

The solutions obtained by GLPK are not in a format presentable to the client. It is as important to present our solutions clearly as it is to get accurate solutions. We need to make sure that when we deliver our solutions, they are in a context that clients can easily relate to.

In a presentation for the DCR and its regional managers from each office, we gave a brief description of our model and how it worked and also presented the solutions as handouts. Since the goal was to minimize costs; we showed a cost comparison between the several cases we considered. We also showed them a glimpse of the kinds of changes that have occurred, so they can analyze if the costs were worth incorporating these changes.

The following map gives the assignment suggested by our study (marked using colors) as compared to the existing assignment (denoted by solid red lines along the boundaries of the regional offices).

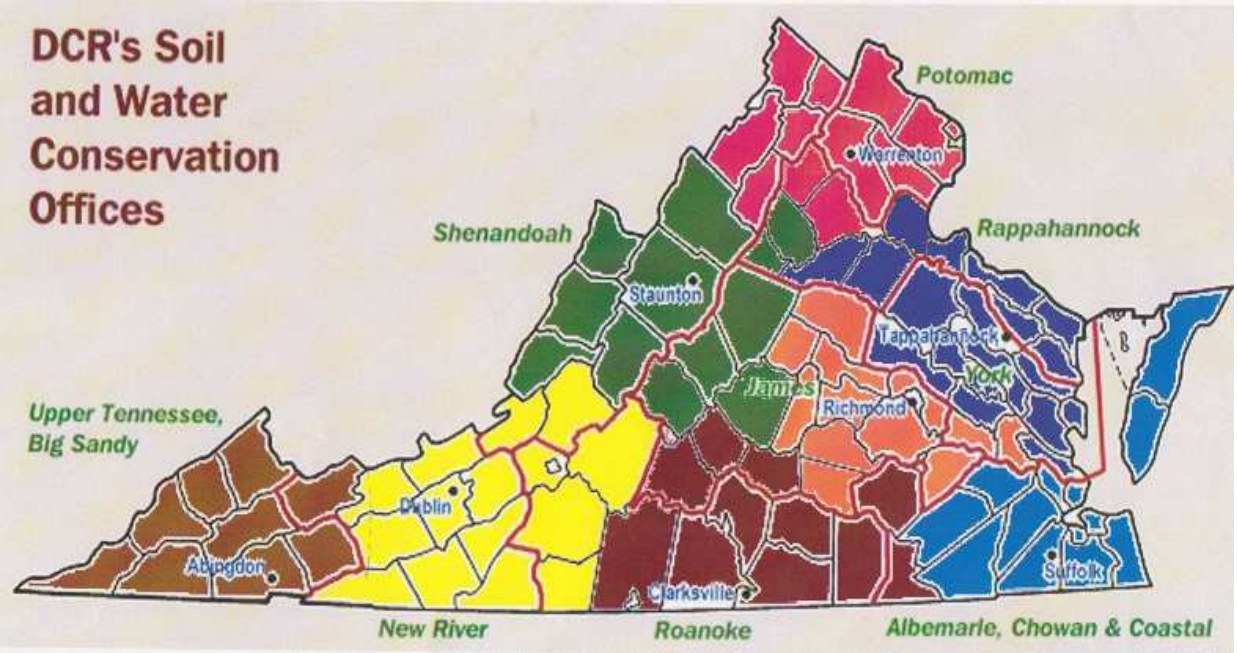

Figure 2: Map showing comparison between existing assignment and our result.

Some of the current assignments in DCR are made based on certain political, socio-economic factors that can have a strong impact. Our solution might have resulted in a change for that assignment, which may not be acceptable. Also, there are many things such as goodwill of farm owners and other clients that is earned over the years of support and service rendered by a regional office that cannot be incorporated into the model. It is difficult to analyze and account for such non-quantifiable entities. Therefore, we stressed the assumptions and limitations of our model and the domain in which it would work. Our solutions provided much fodder for discussion among the managers of the DCR. They came up with a proposal (presented in Appendix D) for the final set of assignments, which was very similar to the assignment without SWCD that we had generated. We also evaluated the costs for their final assignment which was $24,582 more than our proposed assignment. We would like to point out that, this is still a substantial cost savings as compared to the existing assignment.

The following map gives the assignment suggested by our study (marked using colors) as compared to the final assignment (denoted by solid red lines along the boundaries of the regional offices). This final assignment is effective from July 1st 2009.

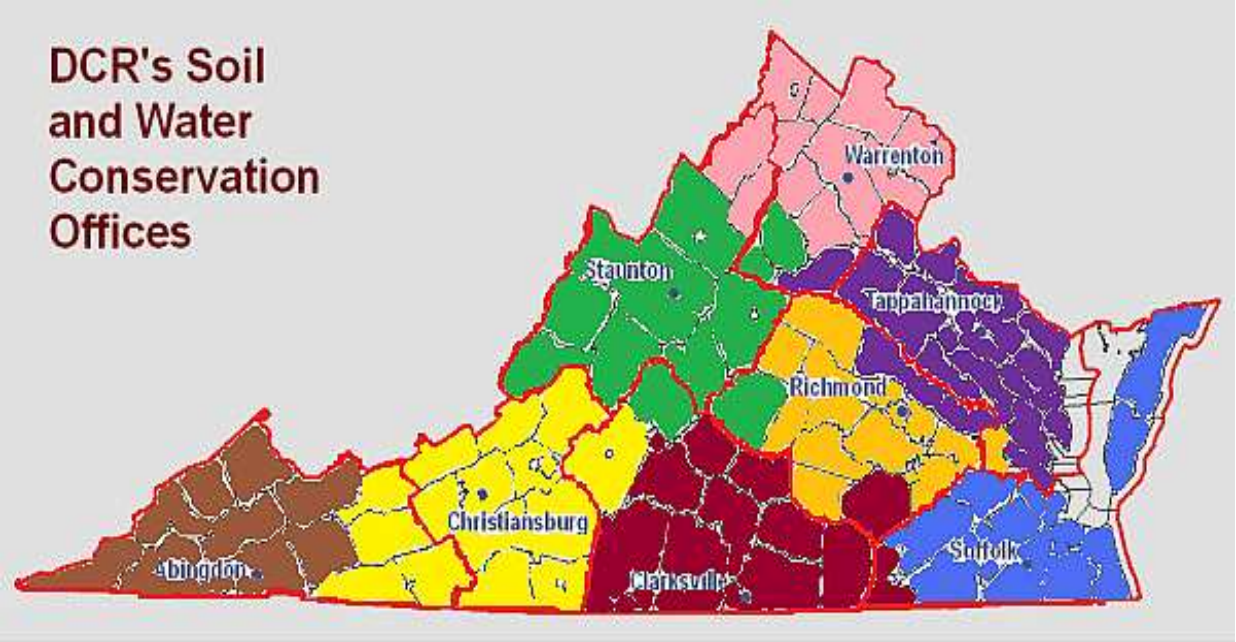

Figure 3: Map showing comparison between final assignment and our result.

Note: In Figure 2, the original assignment has Dublin as the regional office, while in Figure 3, the final assignment, had Christiansburg as the regional office.

The maps were obtained from the DCR website, and colored using imaging software.

CONCLUSION

This study was conducted for DCR to compare different possible assignments of localities to regional offices. All the solutions obtained are based on the data collected by the DCR. Mathematical programming has been used in several fields to find optimal solutions to problems. We have used mathematical programming methods to model this problem. The solutions are only suggestions and may or may not be implemented. Our model chooses the "cheapest" solution based on the given data and assumptions and declares it to be the most cost-efficient solution. We understand that goodwill, political considerations and customary practices are hard to give up. We firmly believe that change should not take place for the sake of change.

Scope for the Future

This study is just a beginning, a step in the direction of finding an analytical way to confirm and reassure ourselves of the decisions we make. There is a lot of scope for future enhancements.

We could further investigate the SWCDs by looking at our solutions and testing for various cases by altering the restrictions on keeping the districts together. We had analyzed as an example of localities that had been swapped between Richmond & Staunton offices and Tappahannock & Richmond offices. We could also keep some districts together and analyze how it affects costing.

There is the prospect of opening new offices and/or closing existing offices. We will have to figure out the service area boundaries and evaluate the costs. There could also be the question of placing new hires in regional offices. We would then have to analyze

how to account for the increase in resource and see how it reflects on the cost and if it changes any existing assignment.

The Nutrient Management program area is vast and has ample scope for study. Most of the folks in this program area visit localities outside their regional office. So we can try modeling by considering Nutrient Management as a separate entity and then combine the results from the two models to arrive at our solution. There will be two models, one with nutrient management as the only program area, and the other with remaining program areas. Both solutions would then have to be integrated and analyzed.

Tele-working seems to be the topic of interest to DCR. Most employees have to attend jobs that are on sites away from their regional offices and probably closer to where they live. There is much time and fuel spent on travel back and forth. There are many people that would like to work from home. Tele-working would provide them with an opportunity to do the same. They would have to directly go to the site for their job. This would be an interesting proposition, as we would then have to treat each individual as a regional office with a certain capacity (resource). Employees will be mobile regional offices that can service a certain number of sites within a boundary. Data collection will be a herculean task for modeling this scenario. Information about each individual's residence and the sites within a defined radius has to be collected. Also it is person-specific, as each individual has a different capacity. The advantage of this scenario would be the ease in adding or removing personnel.

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APPENDIX A

Appendix A.1 List of regional offices, SWCDs and localities

Regional Office	SWCDs	Localites
Abingdon	Daniel Boone	Lee County
	Lonesome Pine	Wise County Dickenson County
	Scott County	Scott County
	Big Sandy	Buchanan County
	Clinch Valley	Russell County
	Holston River	Washington County
	Evergreen	Smyth County
Dublin	Tazwell	Tazewell County
	Big Walker	Bland County Wythe County
	New River	Carroll County Grayson County City of Galax
	Skyline	Giles County Pulaski County Montgomery County Floyd County
	Patrick	Patrick County
Clarksville	Blue Ridge	Roanoke County City of Roanoke Franklin County Henry County
	Peaks of Otter	Bedford County City of Bedford
	Pittsylvania	Pittsylvania County
	Lake County	Mecklenburg County Brunswick County
	Halifax	Halifax County
	Southside	Charlotte County Lunenburg County

Staunton	Shenandoah Valley	Rockingham County City of Harrisonburg Page County
	Headwaters	Augusta County City of Staunton City of Waynesboro
	Natural Bridge	Rockbridge County City of Lexington City of Buena Vista
	Lord Fairfax	Shenandoah County Warren County Frederick County City of Winchester Clarke County
	Mountain	Alleghany County Bath County City of Covington Highland County
	Mountain Castles	Craig County Botetourt County

Warrenton	Loudoun	Loudoun County
	John Marshall	Fauquier County
	Northern Virginia	Fairfax County
	Prince William	Prince William County
	Culpeper*	Rappahannock County Madison County Greene County Culpeper County Orange County
	Tri-county/ City*	Stafford County King George County City of Fredericksburg Spotsylvania County

Richmond	Peter Francisco	Buckingham County Cumberland County
	Piedmont	Prince Edward County Nottoway County Amelia County
	Robert E. Lee	Amherst County Campbell County City of Lynchburg

		Appomattox County
	Thomas Jefferson	Nelson County Albemarle County Fluvanna County City of Charlottesville Louisa County
	Henricopolis	Henrico County
	Monacan	Goochland County Powhatan County
	James River	Chesterfield County Prince George County
Tappahannock	Tidewater	Middlesex County Mathews County Gloucester County
	Hanover Caroline	Caroline County Hanover County
	Three Rivers	King William County Essex County King and Queen County
	Northern Neck	Westmoreland County Northumberland County Richmond County Lancaster County
	Colonial	New Kent County Charles City County City of Williamsburg James City County York County
Suffolk	Appomattox River	City of Petersburg Dinwiddie County
	Chowan Basin	Sussex County Greensville County Southhampten County
	Eastern Shore	Accomack County Northhampton County
	Peanut	Surry County Isle of Wright County City of Suffolk
	Virginia Dare	City of Chesapeake City of Virginia Beach

Appendix A.2 Number of full-time employees in regional offices per program area.

	Program Areas					
Regional Office	**ES**	**Stormwater**	**Nutrient Mgmt.**	**CDC**	**WFC/TMDL**	**Total**
Abingdon	1	2	0.5	1	1	**5.5**
Clarksville	1	1	1	1	0.5	**4.5**
Dublin	1	2	1	1	0.5	**5.5**
Richmond	3	2	1	1	2	**9**
Suffolk	2	2	3	1	1	**9**
Tappahannock	2	3	2	1	1	**9**
Warrenton	1	2	2	1	1	**7**
Staunton	2	2	5	1	1	**11**

Appendix A.3a

Distance (miles) and Drive Time (hrs) from Regional Offices to localities within 90 min. drive time.

Distances are Road Miles measured from the County seat of each locality or a city.

Information obtained from Rand McNally.com.

Localities that are currently in office service area

Localities (that are not currently in service area) that are within approx. 90 miles of regional office

Localities that could be served by another regional office

		miles	***Time***	***miles***	***time***	***miles***	***time***	***miles***	***time***
Localities	**County seat**	Abingdon		Dublin		Clarksville		Staunton	
Accomack County	Accomack								
Albemarle County	***Charlottesville***					117	2.53	***37***	***0.66***
Alleghany County	Covington			91	1.88			74	1.2
Amelia County	Amelia					74	1.42	108	1.95
Amherst County	***Amherst***			122	2.17	98	1.9	***56***	***1.08***
Appomattox County	***Appomatox***					***67***	***1.35***	75	1.56
Arlington County	Arlington								
Augusta County	Staunton							0	0
Bath County	Warm Springs			121	2.55			57	1.32
Bedford County	***Bedford***			81	1.53	***101***	***2.2***	***77***	***1.48***
Bland County	Bland	69	1.12	33	0.65				
Botetourt County	***Fincastle***			***63***	***1.12***	163	3.22	***69***	***1.22***
Brunswick County	Lawrencewille					46	0.87		
Buchanan County	Grundy	78	1.57	129	2.35				
Buckingham County	***Buckingham***					80	1.67	***66***	***1.3***
Campbell County	***Rustburg***			110	2.13	***70***	***1.53***	80	1.53
Caroline County	Bowling Green								
Carroll County	Hillsville	86	1.38	45	0.83				
Charles City County	***Charles City***								
Charlotte County	Charlotte					39	0.82	115	2.13
Chersterfield County	Chesterfield					105	1.8		
City of Alexandria	City of Alexandria								

Cify of Colonial Heights	City of Colonial Heights								
City of Bedford	***City of Bedford***					***101***	***2.2***	***78***	***1.53***
City of Bristol	City of Bristol	17	0.38						
City of Buena Vista	City of Buena Vista			96	1.58	123	2.47	40	0.72
City of Charlottesville	***City of Charlottesville***							***39***	***0.73***
City of Cheaspeak	City of Chesapeake								
City of Clifton Forge	City of Clifton Forge			93	1.92			64	1.08
City of Colonial Heights	City of Colonial Heights								
City of Covington	City of Covington			91	1.88			75	1.26
City of Emporia	City of Emporia					64	1.32		
City of Fairfax	City of Fairfax								
City of Falls Church	City of Falls Chruch								
City of Franklin	City of Franklin					99	1.93		
City of Fredericksburg	***City of Fredericskburg***							111	2.18
City of Hampton	City of Hampton								
City of Harrisonburg	City of Harrisonburg							28	0.61
City of Lexington	City of Lexington			96	1.57			35	0.66
City of Lynchburg	**City of Lynchburg**					***88***	***1.8***		
City of Manassas	City of Manassas								
City of Manassas Park	City of Manassas Park								
City of Newport News	City of Newport News								
City of Norfolk	City of Norfolk								
City of Norton	City of Norton	49	1						
City of Petersburg	***City of Petersburg***					85	1.45		
City of Poquoson	**City of Poquoson**								
City of Portsmouth	City of Portsmouth								
City of Radford	City of Radford	92	1.47	9	0.2				
City of Richmond	City of Richmond								
City of Roanoke	***City of Roanoke***			***54***	***0.9***	***130***	***2.75***	86	1.47
City of Salem	***City of Salem***			***44***	***0.75***	***135***	***2.91***	86	1.48
City of Staunton	City of Staunton							0	0
City of Suffolk	City of Suffolk								
City of Virginia Beach	City of Virginia Beach								
City of Waynesboro	City of Waynesbora							14	0.36
City of Williamsburg	***City of Williamsburg***								
City of Winchester	***City of Winchester***							***95***	***1.65***
Clarke County	***Berryville***							***103***	***0.72***
Craig County	***New Castle***			***58***	***1.13***			***102***	***1.73***

Culpeper County	***Culpeper***							80	1.53
Cumberland County	Cumberland					75	1.55	88	1.72
Dickenson County	Clintwood	60	1.35						
Dinwiddie County	***Dinwiddie***					70	114		
Essex County	Tappahannock								
Fairfax County	Fairfax								
Fauquier County	Warrenton							118	1.98
Floyd County	Floyd	113	1.9	33	0.67				
Fluvanna County	***Palmyra***					123	2.48	***59***	***1***
Franklin County	***Rocky Mount***			***78***	***1.42***	***117***	***2.67***	110	1.93
Frederick County	***Winchester***							***93***	***1.55***
Giles County	Pearisburg	104	1.77	20	0.45				
Gloucester County	Gloucester								
Goochland County	Goochland					100	1.88	81	1.37
Grayson County	Independence	70	1.38	59	1.16				
Greene County	***Standardsville***							59	1.17
Greensville County	Emporia					66	1.33		
Halifax County	Halifax					27	0.55		
Hanover County	Hanover							115	1.87
Henrico County	Richmond					109	1.88		
Henry County	***Martinsville***			***77***	***1.72***	***85***	***1.75***		
Highland County	Monterey							49	1.15
Hopewell County	Hopewell								
Isle of Wright County	Isle of Wight								
James City County	***Williamsburg***								
King and Queen County	King and Queen								
King George County	King George								
King William County	King William								
Lancaster County	Lancaster								
Lee County	Jonesville	79	1.6						
Loudoun County	Leesburg							129	2.36
Louisa County	Louisa								
Lunenburg County	Luneburg					34	0.77		
Madison County	***Madison***							63	1.16
Mathews County	Mathews								
Mecklenburg County	Boydton					12	0.23		
Middlesex County	Saluda								
Montgomery County	Christiansburg	99	1.58	19	0.35				

Nelson County	***Lovingston***					114	2.16	***38***	***0.73***
New Kent County	***New Kent***								
Northhampton County	Eastville								
Northumberland County	Heathsville								
Nottoway County	Nottoway					66	1.32	121	2.35
Orange County	***Orange***							72	1.26
Page County	***Luray***							***57***	***1.06***
Patrick County	Stuart			59	1.25				
Pittsylvania County	Chatham			117	2.3	66	1.37		
Powhatan County	Powhatan					91	1.78	93	1.66
Prince Edwards County	***Farmville***					***56***	***1.17***	95	1.86
Prince George County	Charles City					114	2.27		
Prince William County	Manassas								
Pulaski County	Pulaski	79	1.28	7	0.15				
Rappahannock County	***Washington***							79	1.56
Richmond County	Warsaw								
Roanoke County	***Salem***			***44***	***0.75***	***135***	***2.91***	85	1.42
Rockbridge County	Lexington			96	1.57	131	2.63	35	0.58
Rockingham County	Harrisonburg							26	0.52
Russell County	Lebanon	21	0.46	105	1.8				
Scott County	Gate City	43	0.87						
Shenandoah County	Woodstock							***64***	***1***
Smyth County	Marian	29	0.5	56	0.88				
Southhampton County	Courtland					92	1.81		
Spotsylvania County	***Spotsylvania***							106	2.05
Stafford County	***Stafford***								
Surry County	Surry								
Sussex County	Sussex					85	1.57		
Tazewell County	Tazewell	58	1.15	82	1.43				
Warren County	***Front Royal***							***88***	***1.5***
Washington County	Abingdon	0	0	84	1.33				
Westmoreland County	Montross								
Wise County	Wise	53	1.06						
Wythe County	Wytheville	56	0.9	29	0.5				
York County	Yorktown								

Appendix A.3b

Distance (miles) and Drive Time (hrs) from Regional Offices to localities within 90 min. drive time.

Distances are Road Miles measured from the County seat of each locality or a city.

Information obtained from Rand McNally.com.

Localities that are currently in office service area

Localities (that are not currently in service area) that are within approx. 90 miles of regional office

Localities that could be served by another regional office

		miles	***time***	***miles***	***time***	***miles***	***time***	***miles***	***time***
Localities	**County seat**	Warrenton		Richmond		Tappahannock		Suffolk	
Accomack County	Accomack							69	2.25
Albemarle County	***Charlottesville***	71	1.56	***70***	***1.22***	110	2		
Alleghany County	Covington								
Amelia County	Amelia			41	0.85	86	1.8	110	2.33
Amherst County	***Amherst***			***120***	***2.1***				
Appomattox County	***Appomatox***			***94***	***1.8***				
Arlington County	Arlington	45	1.03			103	2.03		
Augusta County	Staunton	121	2.06						
Bath County	Warm Springs								
Bedford County	***Bedford***								
Bland County	Bland								
Botetourt County	***Fincastle***								
Brunswick County	Lawrencewille			72	1.25			76	1.58
Buchanan County	Grundy								
Buckingham County	***Buckingham***	108	2.43	***72***	***1.55***				
Campbell County	***Rustburg***			***112***	***2.15***				
Caroline County	Bowling Green	62	1.45	42	0.78	38	0.82		
Carroll County	Hillsville								
Charles City County	***Charles City***			***37***	***0.78***	***72***	***1.52***	94	1.88
Charlotte County	Charlotte			87	1.72	131	2.66		
Chersterfield County	Chesterfield	112	2.08	20	0.38	65	1.32	80	1.75
City of Alexandria	City of Alexandria	50	1.05			99	1.97		

Cify of Colonial Heights	City of Colonial Heights			22	0.43	67	1.38	63	1.47
City of Bedford	***City of Bedford***								
City of Bristol	City of Bristol								
City of Buena Vista	City of Buena Vista								
City of Charlottesville	***City of Charlottesville***	71	1.56	***70***	***1.22***				
City of Cheaspeak	City of Chesapeake			106	1.87	107	2.18	23	0.67
City of Clifton Forge	City of Clifton Forge								
City of Colonial Heights	City of Colonial Heights			22	0.43	67	1.37	63	1.47
City of Covington	City of Covington								
City of Emporia	City of Emporia			67	1.2	113	2.03	57	1.27
City of Fairfax	City of Fairfax	30	0.71			96	2.02		
City of Falls Church	City of Falls Chruch	40	0.93			102	2.05		
City of Franklin	City of Franklin							22	0.58
City of Fredericksburg	***City of Fredericskburg***	***38***	***0.96***	59	1.03	***47***	***1.08***		
City of Hampton	City of Hampton			77	1.3	78	1.62	34	0.82
City of Harrisonburg	City of Harrisonburg	95	1.65						
City of Lexington	City of Lexington								
City of Lynchburg	**City of Lynchburg**			***116***	***2.26***				
City of Manassas	City of Manassas	22	0.58	96	1.75	91	1.95		
City of Manassas Park	City of Manassas Park	24	0.78	96	1.75	91	1.95		
City of Newport News	City of Newport News			80	1.32	81	1.63	27	0.65
City of Norfolk	City of Norfolk			93	1.65	94	1.97	20	0.55
City of Norton	City of Norton								
City of Petersburg	***City of Petersburg***			***24***	***0.45***	68	1.38	***60***	***1.42***
City of Poquoson	**City of Poquoson**			72	1.23	***71***	***1.43***	***40***	***0.98***
City of Portsmouth	City of Portsmouth			95	1.68	96	2	19	0.5
City of Radford	City of Radford								
City of Richmond	City of Richmond			0	0	46	0.98	84	1.85
City of Roanoke	***City of Roanoke***								
City of Salem	***City of Salem***								
City of Staunton	City of Staunton	121	2.06						
City of Suffolk	City of Suffolk			85	1.83	105	2.23	0	0
City of Virginia Beach	City of Virginia Beach			106	1.87	107	2.17	34	0.85
City of Waynesboro	City of Waynesbora								
City of Williamsburg	***City of Williamsburg***			***52***	***0.88***	***72***	***1.42***	61	1.27
City of Winchester	***City of Winchester***	***55***	***1.05***						
Clarke County	***Berryville***	***38***	***1.03***						
Craig County	***New Castle***								

Culpeper County	***Culpeper***	***25***	***0.6***	89	1.75	***84***	***1.93***		
Cumberland County	Cumberland	108	2.43	53	1.13	101	2.03		
Dickenson County	Clintwood								
Dinwiddie County	***Dinwiddie***			***40***	***0.75***	85	1.68	***76***	***1.68***
Essex County	Tappahannock	89	1.95	46	1	0	0	108	2.25
Fairfax County	Fairfax	30	0.71	101	1.82	96	2.02		
Fauquier County	Warrenton	0	0			89	1.96		
Floyd County	Floyd								
Fluvanna County	***Palmyra***	73	1.65	***64***	***1.1***	104	1.88		
Franklin County	***Rocky Mount***								
Frederick County	***Winchester***	***55***	***1.05***						
Giles County	Pearisburg								
Gloucester County	Gloucester			59	1.13	45	0.85	64	1.43
Goochland County	Goochland	86	1.93	32	0.63	72	1.42		
Grayson County	Independence								
Greene County	***Standardsville***	***56***	***1.21***	86	1.57	***114***	***2.38***		
Greensville County	Emporia			67	1.25			57	1.27
Halifax County	Halifax								
Hanover County	Hanover	82	1.58	***24***	***0.45***	***42***	***0.87***	102	2.13
Henrico County	Richmond	93	1.75	0	0			84	1.85
Henry County	***Martinsville***								
Highland County	Monterey								
Hopewell County	Hopewell			22	0.5	64	1.25		
Isle of Wright County	Isle of Wight			74	1.58	99	2.12	20	0.6
James City County	***Williamsburg***			***52***	***0.88***	***72***	***1.42***	61	1.27
King and Queen County	King and Queen	109	2.25	43	0.97	19	0.42	105	2.1
King George County	King George	58	1.33	62	1.22	36	0.73		
King William County	King William	98	2.01	32	0.75	25	0.55	101	2
Lancaster County	Lancaster			79	1.58	30	0.67	105	2.3
Lee County	Jonesville								
Loudoun County	Leesburg	34	0.83			130	2.5		
Louisa County	Louisa	58	1.32	55	1.05	95	1.85		
Lunenburg County	Luneburg			75	1.55				
Madison County	***Madison***	***42***	***0.92***	86	1.61	***102***	***2.18***		
Mathews County	Mathews			73	1.5	53	1.13	79	1.81
Mecklenburg County	Boydton			97	1.65				
Middlesex County	Saluda			53	1.02	29	0.55	80	1.72
Montgomery County	Christiansburg								

Nelson County	***Lovingston***	100	2.11	***102***	***2.1***				
New Kent County	***New Kent***			***29***	***0.55***	***54***	***1.13***	82	1.58
Northhampton County	Eastville							69	1.58
Northumberland County	Heathsville			71	1.57	25	0.57	117	2.6
Nottoway County	Nottoway			61	1.27	106	2.2	103	2.32
Orange County	***Orange***	***43***	***1***	76	1.35	***87***	***1.83***		
Page County	***Luray***	***44***	***1.05***						
Patrick County	Stuart								
Pittsylvania County	Chatham								
Powhatan County	Powhatan	98	2.25	34	0.75	82	1.7		
Prince Edwards County	***Farmville***			***66***	***1.33***				
Prince George County	Charles City			24	0.45	68	1.38	94	1.88
Prince William County	Manassas	22	0.58	96	1.75	91	1.95		
Pulaski County	Pulaski								
Rappahannock County	***Washington***	***22***	***0.5***	119	2.2	***111***	***2.48***		
Richmond County	Warsaw			53	1.15	7	0.08	115	2.4
Roanoke County	***Salem***								
Rockbridge County	Lexington								
Rockingham County	Harrisonburg	95	1.65						
Russell County	Lebanon								
Scott County	Gate City								
Shenandoah County	Woodstock	***56***	***1.03***						
Smyth County	Marian								
Southhampton County	Courtland			67	1.25	114	2.08	30	0.71
Spotsylvania County	***Spotsylvania***	***47***	***1.13***	59	1.03	***54***	***1.22***		
Stafford County	***Stafford***	***42***	***0.96***	67	1.08	***62***	***1.28***		
Surry County	Surry			53	1.2	95	1.95	38	1
Sussex County	Sussex							55	1.2
Tazewell County	Tazewell								
Warren County	***Front Royal***	***33***	***0.75***						
Washington County	Abingdon								
Westmoreland County	Montross	84	1.87	65	1.42	19	0.4		
Wise County	Wise								
Wythe County	Wytheville								
York County	Yorktown			64	1.12	59	1.12	50	1.15

Appendix A.4

Total number of trips and hours required to serve each locality by program (annual total).

Hours do not include travel time, hours do include both onsite and office work required in that program.

Appendix A.4a
Abingdon Regional Office

	E&S			SW	*Nut Man*		*SWCDS*		*Other*	
Localities	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs**	**# trips**	**total hrs**
Town of Abingdon	6	20	6	10	0	0	0	0	4	4
Town of Bluefield	3	10	2	10	0	0	0	0	5	10
City of Bristol	8	30	8	16	1	4	0	0	8	60
Buchanan County	10	40	3	10	0	0	12	80	20	80
Dickenson County	5	40	4	10	4	8	16	80	20	80
Lee County	5	30	1	10	10	20	12	72	6	80
City of Norton	10	50	10	60	0	0	0	0	2	10
Russell County	15	80	80	480	10	20	12	80	2	80
Scott County	15	60	5	15	10	20	12	80	2	15
Smyth County	10	60	20	80	5	10	12	80	2	80
Tazwell County	10	60	7	60	10	20	2	10	10	60
Washington County	30	150	60	672	20	60	12	80	10	100
Wise County	35	80	25	240	2	6	12	80	6	100
	162	**710**	**231**	**1,673**	**72**	**168**	**102**	**642**	**97**	**759**

Appendix A.4b

Christiansburg

	E&S		*Storm water*		*Nut Man*		*SWCDS*		*Other*	
Localities	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs**	**# trips**	**total hrs**
Patrick County	5	19	4	43	4	50	14	100		
Grayson County	41	124	5	232			12	61		
Carroll County	10	48	33	399			2	15	1	3
Montgomery County	15	74	9	121	10	80	24	178	11	140
Town of Christiansburg	14	64	37	484			0	0	7	109
Floyd County	2	8	1	15	2	3	1	6		0
Town of Blacksburg	71	354	21	485	2	6	0	0	21	265
Town of Pulaski	4	16	15	114	0	0	0	0	6	93
Wythe County	5	30	8	53	5	60	4	10	1	16
Town of Wytheville	20	35	4	27			11	84	4	62
Town of Dublin	9	48	5	117			1	5	11	159
Galax County	3	42	1	22			19	154		0

Giles County	10	40	13	161			1	5	5	78
Pulaski County	2	10	2	74	5	53	2	10		0
Bland County	2	10	1	40			7	20		0
Town of Narrows	4	18					0	0		0
Town of Pearisburg	6	26					0	0		0
City of Radford	41	130	1	15	0	0	3	25	13	202
Tazewell					2	4	22	143	1	16
Franklin County					15	209				
Bedford County					1	8				
Pittsylvania County					2	50				
Total	**264**	1096	160	2402	48	523	123	816	81	1,143

Appendix A.4c

Staunton

	E&S		***Storm water***		***Nut Man***		***SWCDS***		***Other***	
Localities	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs**	**# trips**	**total hrs**
Augusta County	51	242	70.00%	456	186	2806	20	240	5	15
Town of Berryville	1	4	8	53						
Botetourt County	3	14	9	68	27	403	16	200	2	7
Town of Bridgewater	3	5	12	53					4	12
Clarke County	4	4	16	106			1	2	1	3
Frederick County	14	195	19	198			1	2	4	14
City of Harrisonburg	26	375	54	567			12	280	15	40
City of Lexington	31	12	37	375			15	220	8	20
Rockbridge County	36	63	6	68	26	450	3	6	1	2
Rockingham County	20	225	14	194	325	3175	4	8	10	25
City of Staunton	36	77	7	82			10	20	15	30
Warren County	16	2	7	121			1	2	2	5
City of Waynesboro	5	22	14	199			0	0	10	20
City of Winchester	6	7	5	39			0	0	12	28
Town of Woodstock	6	7	4	39			4	4	1	2
City of Buena Vista	6	26	3	27			0	0	3	6
Shenandoah County	8	100	9	97	8	120	2	4	10	25
Page County	8	100	14	170	13	176	4	8	15	40
Alleghany County	32	49	4	24	6	94	1	2	4	8
Bath County	32	12	26	136	9	72	14	180	2	6
Craig County	3	18	3	12	7	104	1	2		
Highland County	5	23	9	100	16	266	1	2	1	4
Town of Stephens City	2	3	3	12			20	400	2	7
City of Clifton Forge	3	18	2	12			0	0	2	7
City of Covington	3	18	2	12			0	0	3	10
	360	**1,621**	**288**	**3,220**	**623**	**7,666**	**130**	**1,582**	**132**	**336**

Appendix A.4d

Clarksville

	E&S		*Storm water*		*Nut Man*		*SWCDS*		*Other*	
Localities	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs**	**# trips**	**total hrs**
Bedford County	13	94	17	166	20	205	10	206		
Pittsylvania County	9	63	7	38	20	205	13	250		
City of Salem	6	46	4	40						
Town of Rocky Mount	6	53	4	19						
Mecklenburg County	14	48	20	238	2	20	10	203	1	4
City of Roanoke	4	16	5	61					12	186
Roanoke County	10	66	10	110	1	10	1	80	4	82
Franklin County	11	57	9	89	26	264	10	204		0
Henry County	4	54	7	142	2	20	1	80		0
Halifax County	14	54	10	76	12	125	15	250	1	16
Town of Martinsville	8	48	0	0					1	16
Town of Danville	12	39	30	330			1	6		0
City of Bedford	2	9	11	193						
Town of South Hill	14	56	5	54						
Charlotte County	14	76	3	14	10	100	14	200		
Lunenburg County	6	35	1	4	5	50	1	80		
Brunswick County	10	54	9	123	5	50	1	80		
Town of South Boston									1	6
Town of Alta Vista										
Town of Chase City										
									1	16
									1	16
	157	**868**	**152**	**1,697**	**103**	**1,049**	**77**	**1,639**	**22**	**342**

Appendix A.4e

Warrenton

	E&S		*Storm water*		*Nut Man*		*SWCDS*		*Other*	
Localities	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs**	**# trips**	**total hrs**
Alexandria City	24	24	10	65			0	0	22	98
Town of Dumfries	5	20	3	20			0	0	3	6
Fairfax County	56	438	57	324	15	105	18	265	50	244
Fauquier County	22	55	36	228	40	280	19	320	44	40
Town of Haymarket	7	7	3	20			0	0	3	6
Loudoun County	27	100	53	337	40	280	19	277	30	117

Prince William County	37	325	52	333	30	210	18	256	60	216
Town of Vienna	3	7	3	20			0	0	3	6
Town of Warrenton	8	15	5	32			0	0	12	25
City of Manassas Park	3	3	3	20	10	70	0	0	3	6
City of Manassas	3	4	5	32	5	35	0	0	10	66
Town of Occoquan	3	6	3	20			0	0	8	22
Arlington County	28	28	11	68			0	0	20	87
City of Falls Church	3	10	3	20			0	0	20	87
City of Fairfax	3	5	3	20			0	0	25	80
Town of Herndon	3	7	3	20			0	0	3	9
Clarke County *					10*	83*				
Frederick County*					8*	66*				
Warren County*					2*	16*				
Shenandoah County*					30*	497*				
Page County*					72*	995*				
Orange County **							4	66		
Culpepper County **							4	66		
Madison County **							4	66		
Rappahannock County **							4	66		
Greene County **							4	66		
Spotsylvania Co. **							5	87		
Stafford County **							5	85		
King George County **							5	90		
City of Fredericksburg **							5	84		
	235	**1,054**	**253**	**1,579**	**140**	**980**	**114**	**1,794**	**316**	**1,115**

* Localities are in the Staunton Office service area. Nutrient management services for these localities are provided from the Warrenton office.

**Localities are in the Tappahannock service area. All Soil and Water Conservation District coordination functions for these localities provided from the Warrenton office.

Appendix A.4f

Richmond

	E&S		***Storm water***		***Nut Man***		***SWCDS***		***Other***	
Localities	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs**	**# trips**	**total hrs**
Albemarle County	2	10	81	261	0	0	7	48	5	90
Amelia County	2	35	29	130	19	350	1	8	0	0
Amherst County	0	2	11	28	0	0	1	8	0	0
Appomattox County	19	92	12	108	0	0	3	28	0	0
Buckingham County	2	46	2	40	23	408	15	84	4	59
Campbell County	0	4	25	104	6	200	13	44	0	0
City of Charlottesville	37	450	52	510	0	0	12	48	0	0
Chersterfield County	30	343	48	196	1	1	8	52	2	3

Cify of Colonial Heights	1	12	8	134	0	0	0	0	1	5
Cumberland County	7	21	8	33	19	0	2	14	0	0
Town of Farmville	6	132	14	149	0	0	1	6	3	13
Fluvanna County	0	4	24	96	0	0	1	8	0	0
Goochland County	1	12	34	97	0	0	13	70	2	5
Henrico County	13	96	71	227	0	0	16	84	4	78
Hopewell County	1	7	6	36	0	0	0	0	2	4
Louisa County	16	270	42	114	0	0	1	8	1	25
City of Lynchburg	0	4	13	62	0	0	2	16	2	12
Nelson County	2	14	26	71	0	0	1	8	0	0
Nottoway County	3	120	44	255	16	250	1	8	0	0
Powhatan County	1	16	30	148	4	60	2	22	0	0
Prince Edwards County	4	98	40	230	10	290	28	128	6	214
Prince George County	1	8	7	24	4	60	8	52	0	0
Richmond City	41	468	70	264	0	0	0	0	1	2
Town of Scottsville	0	0	0	0	0	0	0	0	1	3
	189	**2,264**	**697**	**3,317**	**102**	**1,619**	**136**	**744**	**34**	**513**

Appendix A.4g

Tappahannock

	E&S		***Storm water***		***Nut Man***		***SWCDS***		***Other***	
Localities	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs**	**# trips**	**total hrs**
1. Caroline County	4	13	17	136	6	170	5	10	4	55
2. Charles City County	28	90	6	26			10	40	1	15
3. Town of Colonial Beach	2	7	6	15					4	15
4. Culpeper County	4	12	12	96	8	200			5	120
5. Town of Culpeper	1	2	4	32	2	60			2	30
6. Essex County	11	63	18	30	24	680	25	200	1	80
7. City of Fredericksburg	19	123	8	64	2	60			6	70
8. Gloucester County	4	40	27	58	6	170	20	200	4	80
9. Greene County	5	36	11	88	6	150			2	40
10. Hanover County			23	184	6	150	20	200	6	120
11. James City County	30	350	42	127	2	60			9	140
12. King George County	3	16	7	56	6	150			4	70
13. King and Queen County	2	25	6	14	12	340	10	40	2	60
14. King William County	5	30	14	70	2	60	10	40	2	60
15. Lancaster County	8	52	13	28	2	60			5	50
16. Madison County	5	21	4	32	6	150			4	40
17. Mathews County	6	220	10	21			5	10	6	60
18. Middlesex County	6	220	14	25	4	120	15	50	3	40
19. New Kent County	3	15	22	52	2	60	25	200	4	60

20. Northumberland County	5	52	5	12	2	60	5	10	3	40
21. Orange County	8	27	17	136	6	150			2	25
22. City of Poquoson	9	75	12	25					6	100
23. Rappahannock County			1	8	6	150			6	130
24. Richmond County	8	40	5	13	6	170	20	400	4	80
25. Spotsylvania County	2	8	24	192	6	150			6	90
26. Stafford County	4	16	25	200	4	100			5	110
27. Town of Tappahannock			16	27			5	10	3	30
28. Westmoreland County	14	105	8	17	4	120	5	10	3	40
29. Town of West Point	2	10	12	23			10	40	4	60
30. City of Williamsburg	35	400	39	82			10	40	3	40
31. York County	6	30	40	91			5	10	6	50
	239	**2,098**	**468**	**1,980**	**130**	**3,540**	**205**	**1,510**	**125**	**2,000**

Appendix A.4h

Suffolk

	E&S		***Storm water***		***Nut Man***		***SWCDS***		***Other***	
Localities	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs.**	**# trips**	**total hrs**	**# trips**	**total hrs**
Accomack County	48	163	70	336	29	814	15	160	20	100
Town of Cape Charles	4	105	5	108	1	8	2	16	3	3
City of Cheaspeak	36	281	44	174	15	130	15.00	144	30	250
Dinwiddie County	35	300	46	188	24	480	14	160	5	50
City of Emporia	3	40	4	58	3	12	8	80	3	10
City of Franklin	6	135	6	40	4	18	4	32	10	100
Greensville County	9	119	12	74	11	198	8	110	3	60
City of Hampton	5	80	7	186	2	14	1	8	10	100
Isle of Wright County	13	165	18	130	37	750	25	120	10	100
City of Newport News	43	147	60	276	1	8	1	8	5	70
City of Norfolk	150	593	198	894	0	0	2	16	10	120
Northhampton County	9	135	13	132	18	460	4	128	20	150
City of Petersburg	24	300	24	13	2	16	4	92	0	0
City of Portsmouth	58	205	74	178	1	8	1	8	20	150
Southhampton County	5	20	7	46	44	830	15	128	10	150
City of Suffolk	8	185	9	128	48	640	20.00	144	5	50
Surry County	12	125	14	66	21	328	10	120	5	60
Sussex County	16	100	10	62	27	385	10	110	3	40
City of Virginia Beach	32	233	35	184	22	324	10	120	15	150
Total	**516**	**3431**	**656**	**3273**	**310**	**5423**	**169**	**1704**	**187**	**1713**

APPENDIX B

Appendix B.1 GLPK MODEL FILE

```
/* Set Declarations */
set L;                          # set of localities
set R;                          # set of Regional offices
set P;                          # set of Program areas
set J;                          # set of soil conservation districts
set D within (J cross L);   # set of all localities in districts

/* Parameter Definitions */
param N {l in L, p in P};   # Yearly man hours required by l in p
param NT {l in L, p in P}; # Yearly trips to l for p
param A {r in R, p in P};  # Yearly man hours available at r in p (#FTE*48*40)
param M {l in L, r in R};   # Mileage to travel from r to l
param TT{l in L, r in R};   # Travel time from r to l
param sal;              # Average annual salary for employee $50,000/total hours
                          worked (48*40)
param smr;              # The state mileage rate
param alpha;            # The weight for mileage component
param beta;             # The weight for travel time component

# Cost per year of assigning l to r
param C {l in L, r in R} := ((alpha*(2*M[l,r]*T[l,r]*smr))+(beta*(2*TT[l,r]*T[l,r]*sal)));
param TCost {l in L, r in R} := ((2*TT[l,r]*T[l,r]*sal)+(2*M[l,r]*T[l,r]*smr));

/* Decision variables */
var x {l in L, r in R} binary >=0; # 1 if locality l is assigned to office r, 0 otherwise
var TTCost {r in R};                # Total travel cost for each regional office
var TMCost {r in R};                # Total salary cost for each regional office
```

```
var Cost {r in R};                  # Total cost per regional office
var TotTT {r in R};                 # Total time travelled per regional office
var TotM {r in R};                  # Total miles travelled per regional office

/* Objective function */
# Assign localities to offices and minimize cost
minimize z: (sum{l in L, r in R}C[l,r]*x[l,r]);

/* Constraints */

# Ensures each locality is assigned to just 1 office
s.t. Assignment{l in L}: sum{r in R}x[l,r] = 1;

# Ensures that the requirement never exceeds the availability
s.t. Availability{r in R, p in P}: ((sum{l in L}(x[l,r]*N[l,p]))+(sum{l in
L}(2*TT[l,r]*x[l,r]*NT[l,p])))<=(A[r,p]);

#Assign same Office for any two localities in same districts
s.t. Conservation{r in R, (j,d1) in D, (j,d2) in D : d1<>d2}: x[d1,r] = x[d2,r];

#Evaluate Total travel time
s.t. TotalTravel{r in R}: sum{l in L}(2*TT[l,r]*T[l,r]*x[l,r]) = TotTT[r];

#Evaluate Total miles
s.t. TotalMiles{r in R}: sum{l in L}(2*M[l,r]*T[l,r]*x[l,r]) = TotM[r];

# Mandatory Assignments
s.t. A1: x["Washington_County","Abingdon"] = 1;
s.t. A2: x["Montgomery_County","Christiansburg"] = 1;
s.t. A3: x["Halifax_County","Clarksville"] = 1;
```

```
s.t. A4: x["Augusta_County","Staunton"] = 1;
s.t. A5: x["City_of_Staunton","Staunton"] = 1;
s.t. A6: x["Fauquier_County","Warrenton"] = 1;
s.t. A7: x["City_of_Richmond", "Richmond"] = 1;
s.t. A8: x["Chesterfield_County","Richmond"] = 1;
s.t. A9: x["Henrico_County","Richmond"] = 1;
s.t. A10: x["Essex_County","Tappahannock"]=1;
s.t. A11: x["City_of_Suffolk","Suffolk"] = 1;
s.t. A12: x["City_of_Chesapeake","Suffolk"] = 1;
s.t. A13: x["City_of_Virginia_Beach","Suffolk"] = 1;
s.t. A14: x["Isle_of_Wright_County","Suffolk"] = 1;

#Cost evaluation per regional office
s.t. TotCost{r in R}: sum{l in L}TCost[l,r]*x[l,r] = Cost[r];
s.t. TotTrCost{r in R}: sum{l in L}(2*TT[l,r]*T[l,r]*sal*x[l,r]) = TTCost[r];
s.t. TotMileCost{r in R}: sum{l in L}(2*M[l,r]*T[l,r]*smr*x[l,r]) = TMCost[r];
```

Appendix B.2 GLPK DATA FILE

set J := "Daniel_Boone" "Lonesome_Pine" "Scott_County" "Big_Sandy" "Clinch_Valley" "Holston_River" "Evergreen" "Tazewell" "Big_Walker" "New_River" "Skyline" "Patrick" "Blue_Ridge" "Peaks_of_Otter" "Pittsylvania" "Lake_County" "Halifax" "Southside" "Shenandoah_Valley" "Headwaters" "Natural_Bridge" "Lord_Fairfax" "Mountain" "Mountain_Castles" "Loudoun" "John_Marshall" "Northern_Virginia" "Prince_William" "Culpeper" "Tri_county_City" "Peter_Francisco" "Piedmont" "Robert_E_Lee" "Thomas_Jefferson" "Henricopolis" "Monacan" "James_River" "Tidewater" "Hanover_Caroline" "Three_Rivers" "Northern_Neck" "Colonial" "Appomattox_River" "Chowan_Basin" "Eastern_Shore" "Peanut" "Virginia_Dare";

set L:= "Accomack_County" "Albemarle_County" "City_of_Alexandria" "Alleghany_County" "Amelia_County" "Amherst_County" "Appomattox_County" "Arlington_County" "Augusta_County" "Bath_County" "Bedford_County" "Bland_County" "Botetourt_County" "Brunswick_County" "Buchanan_County" "Buckingham_County" "Campbell_County" "Caroline_County" "Carroll_County" "Charles_City_County" "Charlotte_County" "Chesterfield_County" "City_of_Colonial_Heights" "City_of_Bedford" "City_of_Bristol" "City_of_Buena_Vista" "City_of_Charlottesville" "City_of_Chesapeake" "City_of_Clifton_Forge" "City_of_Covington" "City_of_Emporia" "City_of_Fairfax" "City_of_Falls_Church" "City_of_Franklin" "City_of_Fredericksburg" "City_of_Hampton" "City_of_Harrisonburg" "City_of_Lexington" "City_of_Lynchburg" "City_of_Manassas" "City_of_Manassas_Park" "City_of_Newport_News" "City_of_Norfolk" "City_of_Norton" "City_of_Petersburg" "City_of_Poquoson" "City_of_Portsmouth" "City_of_Radford" "City_of_Richmond" "City_of_Roanoke" "City_of_Salem" "City_of_Staunton" ”City_of_Suffolk" "City_of_Virginia_Beach" "City_of_Waynesboro" "City_of_Williamsburg" "City_of_Winchester" "Clarke_County" "Craig_County" "Culpeper_County" "Cumberland_County" "Dickenson_County" "Dinwiddie_County" "Essex_County" "Fairfax_County" "Fauquier_County" "Floyd_County" "Fluvanna_County" "Franklin_County" "Frederick_County" "Giles_County" "Gloucester_County" "Goochland_County" "Grayson_County" "Greene_County" "Greensville_County" "Halifax_County" "Hanover_County" "Henrico_County" "Henry_County" "Highland_County" "Hopewell_County" "Isle_of_Wright_County" "James_City_County" "King_and_Queen_County" "King_George_County" "King_William_County" "Lancaster_County" "Lee_County" "Loudoun_County" "Louisa_County" "Lunenburg_County" "Madison_County" "Mathews_County" "Mecklenburg_County" "Middlesex_County" "Montgomery_County" "Nelson_County" "New_Kent_County" "Northhampton_County" "Northumberland_County" "Nottoway_County" "Orange_County" "Page_County" "Patrick_County" "Pittsylvania_County" "Powhatan_County" "Prince_Edward_County" "Prince_George_County" "Prince_William_County" "Pulaski_County" "Rappahannock_County" "Richmond_County" "Roanoke_County" "Rockbridge_County" "Rockingham_County" "Russell_County" "Scott_County" "Shenandoah_County" "Smyth_County" "Southhampton_County" "Spotsylvania_County" "Stafford_County" "Surry_County" "Sussex_County" "Tazewell_County" "Warren_County" "Washington_County" "Westmoreland_County" "Wise_County" "Wythe_County" "York_County";

set D := (Lake_County,Brunswick_County) (Lake_County, Mecklenburg_County) (Daniel_Boone,Lee_County) (Lonesome_Pine,Wise_County) (Lonesome_Pine,Dickenson_County) (Scott_County,Scott_County) (Big_Sandy,Buchanan_County) (Clinch_Valley,Russell_County) (Holston_River,Washington_County) (Evergreen,Smyth_County) (Tazewell,Tazewell_County) (Big_Walker,Bland_County) (Big_Walker,Wythe_County) (New_River,Carroll_County) (New_River,Grayson_County) (Skyline,Giles_County) (Skyline,Pulaski_County) (Skyline,Montgomery_County) (Skyline,Floyd_County) (Patrick,Patrick_County) (Blue_Ridge,Roanoke_County) (Blue_Ridge,City_of_Roanoke) (Blue_Ridge,Franklin_County) (Blue_Ridge,Henry_County) (Peaks_of_Otter,Bedford_County) (Peaks_of_Otter,City_of_Bedford) (Pittsylvania,Pittsylvania_County) (Halifax,Halifax_County) (Southside,Charlotte_County) (Southside,Lunenburg_County) (Shenandoah_Valley,Rockingham_County) (Shenandoah_Valley,City_of_Harrisonburg) (Shenandoah_Valley,Page_County) (Headwaters,Augusta_County) (Headwaters,City_of_Staunton) (Headwaters,City_of_Waynesboro) (Natural_Bridge,Rockbridge_County) (Natural_Bridge,City_of_Lexington) (Natural_Bridge,City_of_Buena_Vista) (Lord_Fairfax,Shenandoah_County) (Lord_Fairfax,Warren_County) (Lord_Fairfax,Frederick_County) (Lord_Fairfax,City_of_Winchester) (Lord_Fairfax,Clarke_County) (Mountain,Alleghany_County) (Mountain,Bath_County) (Mountain,City_of_Covington) (Mountain,Highland_County) (Mountain_Castles,Craig_County) (Mountain_Castles,Botetourt_County) (Loudoun,Loudoun_County) (John_Marshall,Fauquier_County) (Northern_Virginia,Fairfax_County) (Prince_William,Prince_William_County) (Culpeper,Rappahannock_County) (Culpeper,Madison_County) (Culpeper,Greene_County) (Culpeper,Culpeper_County) (Culpeper,Orange_County) (Tri_county_City,Stafford_County) (Tri_county_City,King_George_County) (Tri_county_City,City_of_Fredericksburg) (Tri_county_City,Spotsylvania_County) (Peter_Francisco,Buckingham_County) (Peter_Francisco,Cumberland_County) (Piedmont,Prince_Edward_County) (Piedmont,Nottoway_County) (Piedmont,Amelia_County) (Robert_E_Lee,Amherst_County) (Robert_E_Lee,Campbell_County) (Robert_E_Lee,City_of_Lynchburg) (Robert_E_Lee,Appomattox_County) (Thomas_Jefferson,Nelson_County) (Thomas_Jefferson,Albemarle_County) (Thomas_Jefferson,Fluvanna_County) (Thomas_Jefferson,City_of_Charlottesville) (Thomas_Jefferson,Louisa_County) (Henricopolis,Henrico_County) (Monacan,Goochland_County) (Monacan,Powhatan_County) (James_River,Chesterfield_County)

(James_River,Prince_George_County) (Tidewater,Middlesex_County) (Tidewater,Mathews_County) (Tidewater,Gloucester_County)
(Hanover_Caroline,Caroline_County) (Hanover_Caroline,Hanover_County) (Three_Rivers,King_William_County)
(Three_Rivers,Essex_County) (Three_Rivers,King_and_Queen_County) (Northern_Neck,Westmoreland_County)
(Northern_Neck,Northumberland_County) (Northern_Neck,Richmond_County) (Northern_Neck,Lancaster_County)
(Colonial,New_Kent_County) (Colonial,Charles_City_County) (Colonial,City_of_Williamsburg) (Colonial,James_City_County)
(Colonial,York_County) (Appomattox_River,City_of_Petersburg) (Appomattox_River,Dinwiddie_County)
(Chowan_Basin,Sussex_County) (Chowan_Basin,Greensville_County) (Chowan_Basin,Southhampton_County)
(Eastern_Shore,Accomack_County) (Eastern_Shore,Northhampton_County) (Peanut,Surry_County) (Peanut,Isle_of_Wright_County)
(Peanut,City_of_Suffolk) (Virginia_Dare,City_of_Chesapeake) (Virginia_Dare,City_of_Virginia_Beach);

set R := "Abingdon" "Clarksville" "Christiansburg" "Richmond" "Suffolk" "Tappahannock" "Warrenton" "Staunton";

set P := "ES" "Stormwater" "Nutmgmt" "CDC" "WFC";

param sal := 26;

param smr := 0.585;

param beta := 0.8;

param alpha := 0.2;

param N : ES Stormwater Nutmgmt CDC WFC :=
Accomack_County 163 336 814 160 100
Albemarle_County 10 261 0 48 90
Alleghany_County 49 24 94 2 8
Amelia_County 35 130 350 8 0
Amherst_County 2 28 0 8 0
Appomattox_County 92 108 0 28 0
Augusta_County 242 456 2806 240 15
Bath_County 12 136 72 180 6
Bedford_County 94 166 213 206 0
Bland_County 10 40 0 0 0
Botetourt_County 14 68 403 200 7
Brunswick_County 54 123 50 80 0
Buchanan_County 40 10 0 80 80
Buckingham_County 46 40 408 84 59
Campbell_County 4 104 200 44 0
Caroline_County 13 136 170 10 55
Carroll_County 48 399 0 3 3
Charles_City_County 90 26 0 40 15
Charlotte_County 76 14 100 200 0
Chesterfield_County 343 196 1 52 3
City_of_Bedford 9 193 0 0 0
City_of_Buena_Vista 26 27 0 0 6
City_of_Charlottesville 450 510 0 48 0
City_of_Chesapeake 281 174 130 144 250
City_of_Covington 18 12 0 0 10
City_of_Fredericksburg 123 64 60 0 70
City_of_Harrisonburg 375 567 0 280 40
City_of_Lexington 12 375 0 220 20
City_of_Lynchburg 4 62 0 16 12
City_of_Petersburg 300 13 16 92 0
City_of_Roanoke 16 61 0 0 186
City_of_Staunton 77 82 0 20 30
City_of_Suffolk 185 128 640 144 50
City_of_Virginia_Beach 233 184 324 120 150

City_of_Waynesboro 22 199 0 0 20
City_of_Williamsburg 400 82 0 40 40
City_of_Winchester 7 39 0 0 28
Clarke_County 4 106 0 2 3
Craig_County 18 12 104 2 0
Culpeper_County 12 96 200 0 120
Cumberland_County 21 33 0 14 0
Dickenson_County 40 10 8 80 80
Dinwiddie_County 300 188 480 160 50
Essex_County 63 30 680 200 80
Fairfax_County 438 324 105 265 244
Fauquier_County 55 228 280 320 40
Floyd_County 8 15 3 0 0
Fluvanna_County 4 96 0 8 0
Franklin_County 57 89 473 204 0
Frederick_County 195 198 0 2 14
Giles_County 40 161 0 78 78
Gloucester_County 40 58 170 200 80
Goochland_County 12 97 0 70 5
Grayson_County 124 232 0 61 0
Greene_County 36 88 150 0 40
Greensville_County 119 74 198 110 60
Halifax_County 54 76 125 250 16
Hanover_County 0 184 150 200 120
Henrico_County 96 227 0 84 78
Henry_County 54 142 20 80 0
Highland_County 23 100 266 2 4
Isle_of_Wright_County 165 130 750 120 100
James_City_County 350 127 60 0 140
King_and_Queen_County 25 14 340 40 60
King_George_County 16 56 150 0 70
King_William_County 30 70 60 40 60
Lancaster_County 52 28 60 0 50
Lee_County 30 10 20 72 80
Loudoun_County 100 337 280 277 117
Louisa_County 270 114 0 8 25
Lunenburg_County 35 4 50 80 0
Madison_County 21 32 150 0 40
Mathews_County 220 21 0 10 60
Mecklenburg_County 48 238 20 203 4
Middlesex_County 220 25 120 50 40
Montgomery_County 74 121 80 140 140
Nelson_County 14 71 0 8 0
New_Kent_County 15 52 60 200 60
Northhampton_County 135 132 460 128 150
Northumberland_County 52 12 60 10 40
Nottoway_County 120 255 250 8 0
Orange_County 27 136 150 0 25
Page_County 100 170 176 8 40
Patrick_County 19 43 50 100 0
Pittsylvania_County 63 38 255 250 0
Powhatan_County 16 148 60 22 0
Prince_Edward_County 98 230 290 128 214
Prince_George_County 8 24 60 52 0
Prince_William_County 325 333 210 256 216
Pulaski_County 10 74 53 0 0
Rappahannock_County 0 8 150 0 130

Richmond_County 40 13 170 400 80
Roanoke_County 66 110 10 80 82
Rockbridge_County 63 68 450 6 2
Rockingham_County 225 194 3175 8 25
Russell_County 80 480 20 80 80
Scott_County 60 15 20 80 15
Shenandoah_County 100 97 120 4 25
Smyth_County 60 80 10 80 80
Southhampton_County 20 46 830 128 150
Spotsylvania_County 8 192 150 0 90
Stafford_County 16 200 100 0 110
Surry_County 125 66 328 120 60
Sussex_County 100 62 385 110 40
Tazewell_County 60 60 24 26 76
Warren_County 2 121 0 2 5
Washington_County 150 672 60 80 100
Westmoreland_County 105 17 120 10 40
Wise_County 80 240 6 80 100
Wythe_County 30 53 60 16 16
York_County 30 91 0 10 50
City_of_Bristol 30 16 4 0 60
Arlington_County 28 68 0 0 87
Hopewell_County 7 36 0 0 4
City_of_Richmond 468 264 0 0 2
City_of_Salem 46 40 0 0 0
City_of_Poquoson 75 25 0 0 100
City_of_Portsmouth 205 178 8 8 150
City_of_Radford 130 15 0 202 202
City_of_Manassas 4 32 35 0 66
City_of_Manassas_Park 3 20 70 0 6
City_of_Newport_News 147 276 8 8 70
City_of_Norfolk 593 894 0 16 120
City_of_Norton 50 60 0 0 10
City_of_Hampton 80 186 14 8 100
City_of_Clifton_Forge 18 12 0 0 7
City_of_Emporia 40 58 12 80 10
City_of_Fairfax 5 20 0 0 80
City_of_Falls_Church 10 20 0 0 87
City_of_Franklin 135 40 18 32 100
City_of_Alexandria 24 65 0 0 98
City_of_Colonial_Heights 12 134 0 0 5;

param NT : ES Stormwater Nutmgmt CDC WFC :=
Accomack_County 48 70 29 15 20
Albemarle_County 2 81 0 7 5
Alleghany_County 32 4 6 1 4
Amelia_County 2 29 19 1 0
Amherst_County 0 11 0 1 0
Appomattox_County 19 12 0 3 0
Arlington_County 28 11 0 0 20
Augusta_County 51 70 186 20 5
Bath_County 32 26 9 14 2
Bedford_County 13 17 21 10 0
Bland_County 2 1 0 7 0
Botetourt_County 3 9 27 16 2
Brunswick_County 10 9 5 1 0
Buchanan_County 10 3 0 12 20

Buckingham_County 2 2 23 15 4
Campbell_County 0 25 6 13 0
Caroline_County 4 17 6 5 4
Carroll_County 10 33 0 2 1
Charles_City_County 28 6 0 10 1
Charlotte_County 14 3 10 14 0
Chesterfield_County 30 48 1 8 2
City_of_Alexandria 24 10 0 0 22
City_of_Bedford 2 11 0 0 0
City_of_Bristol 8 8 1 0 8
City_of_Buena_Vista 6 3 0 0 3
City_of_Charlottesville 37 52 0 12 0
City_of_Chesapeake 36 44 15 15 30
City_of_Clifton_Forge 3 2 0 0 2
City_of_Colonial_Heights 1 8 0 0 1
City_of_Covington 3 2 0 0 3
City_of_Emporia 3 4 3 8 3
City_of_Fairfax 3 3 0 0 25
City_of_Falls_Church 3 3 0 0 20
City_of_Franklin 6 6 4 4 10
City_of_Fredericksburg 19 8 2 0 6
City_of_Hampton 5 7 2 1 10
City_of_Harrisonburg 26 54 0 12 15
City_of_Lexington 31 37 0 15 8
City_of_Lynchburg 0 13 0 2 2
City_of_Manassas 3 5 5 0 10
City_of_Manassas_Park 3 3 10 0 3
City_of_Newport_News 43 60 1 1 5
City_of_Norfolk 150 198 0 2 10
City_of_Norton 10 10 0 0 2
City_of_Petersburg 24 24 2 4 0
City_of_Poquoson 9 12 0 0 6
City_of_Portsmouth 58 74 1 1 20
City_of_Radford 41 1 0 3 13
City_of_Richmond 41 70 0 0 1
City_of_Roanoke 4 5 0 0 12
City_of_Salem 6 4 0 0 0
City_of_Staunton 36 7 0 10 15
City_of_Suffolk 8 9 48 20 5
City_of_Virginia_Beach 32 35 22 10 15
City_of_Waynesboro 5 14 0 0 10
City_of_Williamsburg 35 39 0 10 3
City_of_Winchester 6 5 0 0 12
Clarke_County 4 16 0 1 1
Craig_County 3 3 7 1 0
Culpeper_County 4 12 8 0 5
Cumberland_County 7 8 19 2 0
Dickenson_County 5 4 4 16 20
Dinwiddie_County 35 46 24 14 5
Essex_County 11 18 24 25 1
Fairfax_County 56 57 15 18 50
Fauquier_County 22 36 40 19 44
Floyd_County 2 1 2 1 0
Fluvanna_County 0 24 0 1 0
Franklin_County 11 9 41 10 0
Frederick_County 14 19 0 1 4
Giles_County 10 13 0 1 5

Gloucester_County 4 27 6 20 4
Goochland_County 1 34 0 13 2
Grayson_County 41 5 0 12 0
Greene_County 5 11 6 0 2
Greensville_County 9 12 11 8 3
Halifax_County 14 10 12 15 1
Hanover_County 0 23 6 20 6
Henrico_County 13 71 0 16 4
Henry_County 4 7 2 1 0
Highland_County 5 9 16 1 1
Hopewell_County 1 6 0 0 2
Isle_of_Wright_County 13 18 37 25 10
James_City_County 30 42 2 0 9
King_and_Queen_County 2 6 12 10 2
King_George_County 3 7 6 0 4
King_William_County 5 14 2 10 2
Lancaster_County 8 13 2 0 5
Lee_County 5 1 10 12 6
Loudoun_County 27 53 40 19 30
Louisa_County 16 42 0 1 1
Lunenburg_County 6 1 5 1 0
Madison_County 5 4 6 0 4
Mathews_County 6 10 0 5 6
Mecklenburg_County 14 20 2 10 1
Middlesex_County 6 14 4 15 3
Montgomery_County 15 9 10 24 11
Nelson_County 2 26 0 1 0
New_Kent_County 3 22 2 25 4
Northhampton_County 9 13 18 4 20
Northumberland_County 5 5 2 5 3
Nottoway_County 3 44 16 1 0
Orange_County 8 17 6 0 2
Page_County 8 14 13 4 15
Patrick_County 5 4 4 14 0
Pittsylvania_County 9 7 22 13 0
Powhatan_County 1 30 4 2 0
Prince_Edward_County 4 40 10 28 6
Prince_George_County 1 7 4 8 0
Prince_William_County 37 52 30 18 60
Pulaski_County 2 2 5 2 0
Rappahannock_County 0 1 6 0 6
Richmond_County 8 5 6 20 4
Roanoke_County 10 10 1 1 4
Rockbridge_County 36 6 26 3 1
Rockingham_County 20 14 325 4 10
Russell_County 15 80 10 12 2
Scott_County 15 5 10 12 2
Shenandoah_County 8 9 8 2 10
Smyth_County 10 20 5 12 2
Southhampton_County 5 7 44 15 10
Spotsylvania_County 2 24 6 0 6
Stafford_County 4 25 4 0 5
Surry_County 12 14 21 10 5
Sussex_County 16 10 27 10 3
Tazewell_County 10 7 10 2 10
Warren_County 16 7 0 1 2
Washington_County 30 60 20 12 10

Westmoreland_County 14 8 4 5 3
Wise_County 35 25 2 12 6
Wythe_County 5 8 5 4 1
York_County 6 40 0 5 6;

param M : Abingdon	Christiansburg		Clarksville	Staunton	Warrenton	Richmond	Tappahannock		Suffolk :=
Accomack_County	20000	20000	20000	20000	20000	20000	20000	69	
Albemarle_County	20000	20000	117	37	71	70	110	20000	
Alleghany_County	20000	91	20000	74	20000	20000	20000	20000	
Amelia_County	20000	20000	74	108	20000	41	86	110	
Amherst_County	20000	122	98	56	20000	120	20000	20000	
Appomattox_County	20000	20000	67	75	20000	94	20000	20000	
Arlington_County	20000	20000	20000	20000	45	20000	103	20000	
Augusta_County	20000	20000	20000	0	121	20000	20000	20000	
Bath_County	20000	121	20000	57	20000	20000	20000	20000	
Bedford_County	20000	81	101	77	20000	20000	20000	20000	
Bland_County	69	33	20000	20000	20000	20000	20000	20000	
Botetourt_County	20000	63	163	69	20000	20000	20000	20000	
Brunswick_County	20000	20000	46	20000	20000	72	20000	76	
Buchanan_County	78	129	20000	20000	20000	20000	20000	20000	
Buckingham_County	20000	20000	80	66	108	72	20000	20000	
Campbell_County	20000	110	70	80	20000	112	20000	20000	
Caroline_County	20000	20000	20000	20000	62	42	38	20000	
Carroll_County	86	45	20000	20000	20000	20000	20000	20000	
Charles_City_County	20000	20000	20000	20000	20000	37	72	94	
Charlotte_County	20000	20000	39	115	20000	87	131	20000	
Chesterfield_County	20000	20000	105	20000	112	20	65	80	
City_of_Alexandria	20000	20000	20000	20000	50	20000	99	20000	
City_of_Bedford	20000	20000	101	78	20000	20000	20000	20000	
City_of_Bristol	17	20000	20000	20000	20000	20000	20000	20000	
City_of_Buena_Vista	20000	96	123	40	20000	20000	20000	20000	
City_of_Charlottesville		20000	20000	20000	39	71	70	20000	20000
City_of_Chesapeake	20000	20000	20000	20000	20000	106	107	23	
City_of_Clifton_Forge		20000	93	20000	64	20000	20000	20000	20000
City_of_Colonial_Heights		20000	20000	20000	20000	20000	22	67	63
City_of_Covington	20000	91	20000	75	20000	20000	20000	20000	
City_of_Emporia	20000	20000	64	20000	20000	67	113	57	
City_of_Fairfax	20000	20000	20000	20000	30	20000	96	20000	
City_of_Falls_Church	20000	20000	20000	20000	40	20000	102	20000	
City_of_Franklin	20000	20000	99	20000	20000	20000	20000	22	
City_of_Fredericksburg		20000	20000	20000	111	38	59	47	20000
City_of_Hampton	20000	20000	20000	20000	20000	77	78	34	
City_of_Harrisonburg	20000	20000	20000	28	95	20000	20000	20000	
City_of_Lexington	20000	96	20000	35	20000	20000	20000	20000	
City_of_Lynchburg	20000	20000	88	20000	20000	116	20000	20000	
City_of_Manassas	20000	20000	20000	20000	22	96	91	20000	
City_of_Manassas_Park		20000	20000	20000	20000	24	96	91	20000
City_of_Newport_News		20000	20000	20000	20000	20000	80	81	27
City_of_Norfolk	20000	20000	20000	20000	20000	93	94	20	
City_of_Norton	49	20000	20000	20000	20000	20000	20000	20000	
City_of_Petersburg	20000	20000	85	20000	20000	24	68	60	
City_of_Poquoson	20000	20000	20000	20000	20000	72	71	40	
City_of_Portsmouth	20000	20000	20000	20000	20000	95	96	19	
City_of_Radford	92	9	20000	20000	20000	20000	20000	20000	
City_of_Richmond	20000	20000	20000	0	46	84	20000	20000	
City_of_Roanoke	20000	54	130	86	20000	20000	20000	20000	

City_of_Salem	20000	44	135	86	20000	20000	20000	20000	
City_of_Staunton	20000	20000	20000	0	121	20000	20000	20000	
City_of_Suffolk	20000	20000	20000	20000	20000	85	105	0	
City_of_Virginia_Beach		20000	20000	20000	20000	20000	106	107	34
City_of_Waynesboro	20000	20000	20000	14	20000	20000	20000	20000	
City_of_Williamsburg		20000	20000	20000	20000	20000	52	72	61
City_of_Winchester	20000	20000	20000	95	55	20000	20000	20000	
Clarke_County	20000	20000	20000	103	38	20000	20000	20000	
Craig_County	20000	58	20000	102	20000	20000	20000	20000	
Culpeper_County	20000	20000	20000	80	25	89	84	20000	
Cumberland_County	20000	20000	75	88	108	53	101	20000	
Dickenson_County	60	20000	20000	20000	20000	20000	20000	20000	
Dinwiddie_County	20000	20000	70	20000	20000	40	85	76	
Essex_County	20000	20000	20000	20000	89	46	0	108	
Fairfax_County	20000	20000	20000	20000	30	101	96	20000	
Fauquier_County	20000	20000	20000	118	0	20000	89	20000	
Floyd_County	113	33	20000	20000	20000	20000	20000	20000	
Fluvanna_County	20000	20000	123	59	73	64	104	20000	
Franklin_County	20000	78	117	110	20000	20000	20000	20000	
Frederick_County	20000	20000	20000	93	55	20000	20000	20000	
Giles_County	104	20	20000	20000	20000	20000	20000	20000	
Gloucester_County	20000	20000	20000	20000	20000	59	45	64	
Goochland_County	20000	20000	100	81	86	32	72	20000	
Grayson_County	70	59	20000	20000	20000	20000	20000	20000	
Greene_County	20000	20000	20000	59	56	86	114	20000	
Greensville_County	20000	20000	66	20000	20000	67	20000	57	
Halifax_County	20000	20000	27	20000	20000	20000	20000	20000	
Hanover_County	20000	20000	20000	115	82	24	42	102	
Henrico_County	20000	20000	109	20000	93	0	20000	84	
Henry_County	20000	77	85	20000	20000	20000	20000	20000	
Highland_County	20000	20000	20000	49	20000	20000	20000	20000	
Hopewell_County	20000	20000	20000	20000	20000	22	64	20000	
Isle_of_Wright_County		20000	20000	20000	20000	20000	74	99	20
James_City_County	20000	20000	20000	20000	20000	52	72	61	
King_and_Queen_County		20000	20000	20000	20000	109	43	19	105
King_George_County	20000	20000	20000	20000	58	62	36	20000	
King_William_County		20000	20000	20000	20000	98	32	25	101
Lancaster_County	20000	20000	20000	20000	20000	79	30	105	
Lee_County	79	20000	20000	20000	20000	20000	20000	20000	
Loudoun_County	20000	20000	20000	129	34	20000	130	20000	
Louisa_County	20000	20000	20000	20000	58	55	95	20000	
Lunenburg_County	20000	20000	34	20000	20000	75	20000	20000	
Madison_County	20000	20000	20000	63	42	86	102	20000	
Mathews_County	20000	20000	20000	20000	20000	73	53	79	
Mecklenburg_County	20000	20000	12	20000	20000	97	20000	20000	
Middlesex_County	20000	20000	20000	20000	20000	53	29	80	
Montgomery_County	99	19	20000	20000	20000	20000	20000	20000	
Nelson_County	20000	20000	114	38	100	102	20000	20000	
New_Kent_County	20000	20000	20000	20000	20000	29	54	82	
Northhampton_County		20000	20000	20000	20000	20000	20000	20000	69
Northumberland_County		20000	20000	20000	20000	20000	71	25	117
Nottoway_County	20000	20000	66	121	20000	61	106	103	
Orange_County	20000	20000	20000	72	43	76	87	20000	
Page_County	20000	20000	20000	57	44	20000	20000	20000	
Patrick_County	20000	59	20000	20000	20000	20000	20000	20000	
Pittsylvania_County	20000	117	66	20000	20000	20000	20000	20000	
Powhatan_County	20000	20000	91	93	98	34	82	20000	

Prince_Edward_County		20000	20000	56	95	20000	66	20000	20000
Prince_George_County		20000	20000	114	20000	20000	24	68	94
Prince_William_County		20000	20000	20000	20000	22	96	91	20000
Pulaski_County	79	7	20000	20000	20000	20000	20000	20000	
Rappahannock_County		20000	20000	20000	79	22	119	111	20000
Richmond_County	20000	20000	20000	20000	20000	53	7	115	
Roanoke_County	20000	44	135	85	20000	20000	20000	20000	
Rockbridge_County	20000	96	131	35	20000	20000	20000	20000	
Rockingham_County	20000	20000	20000	26	95	20000	20000	20000	
Russell_County	21	105	20000	20000	20000	20000	20000	20000	
Scott_County	43	20000	20000	20000	20000	20000	20000	20000	
Shenandoah_County	20000	20000	20000	64	56	20000	20000	20000	
Smyth_County	29	56	20000	20000	20000	20000	20000	20000	
Southhampton_County		20000	20000	92	20000	20000	67	114	30
Spotsylvania_County	20000	20000	20000	106	47	59	54	20000	
Stafford_County	20000	20000	20000	20000	42	67	62	20000	
Surry_County	20000	20000	20000	20000	20000	53	95	38	
Sussex_County	20000	20000	85	20000	20000	20000	20000	55	
Tazewell_County	58	82	20000	20000	20000	20000	20000	20000	
Warren_County	20000	20000	20000	88	33	20000	20000	20000	
Washington_County	0	84	20000	20000	20000	20000	20000	20000	
Westmoreland_County		20000	20000	20000	20000	84	65	19	20000
Wise_County	53	20000	20000	20000	20000	20000	20000	20000	
Wythe_County	56	29	20000	20000	20000	20000	20000	20000	
York_County	20000	20000	20000	20000	20000	64	59	50;	

param TT : Abingdon	Christiansburg	Clarksville	Staunton	Warrenton	Richmond	Tappahannock	Suffolk :=
Accomack_County	20000	20000	20000	20000	20000	20000	2.25
Albemarle_County	20000	20000	2.53	0.66	1.56	1.22	2	20000
Alleghany_County	20000	1.88	20000	1.2	20000	20000	20000	20000
Amelia_County	20000	20000	1.42	1.95	20000	0.85	1.8	2.33
Amherst_County	20000	2.17	1.9	1.08	20000	2.1	20000	20000
Appomattox_County	20000	20000	1.35	1.56	20000	1.8	20000	20000
Arlington_County	20000	20000	20000	20000	1.03	20000	2.03	20000
Augusta_County	20000	20000	20000	0	2.06	20000	20000	20000
Bath_County	20000	2.55	20000	1.32	20000	20000	20000	20000
Bedford_County	20000	1.53	2.2	1.48	20000	20000	20000	20000
Bland_County	1.12	0.65	20000	20000	20000	20000	20000	20000
Botetourt_County	20000	1.12	3.22	1.22	20000	20000	20000	20000
Brunswick_County	20000	20000	0.87	20000	20000	1.25	20000	1.58
Buchanan_County	1.57	2.35	20000	20000	20000	20000	20000	20000
Buckingham_County	20000	20000	1.67	1.3	2.43	1.55	20000	20000
Campbell_County	20000	2.13	1.53	1.53	20000	2.15	20000	20000
Caroline_County	20000	20000	20000	20000	1.45	0.78	0.82	20000
Carroll_County	1.38	0.83	20000	20000	20000	20000	20000	20000
Charles_City_County	20000	20000	20000	20000	20000	0.78	1.52	1.88
Charlotte_County	20000	20000	0.82	2.13	20000	1.72	2.66	20000
Chesterfield_County	20000	20000	1.8	20000	2.08	0.38	1.32	1.75
City_of_Alexandria	20000	20000	20000	20000	1.05	20000	1.97	20000
City_of_Bedford	20000	20000	2.2	1.53	20000	20000	20000	20000
City_of_Bristol	0.38	20000	20000	20000	20000	20000	20000	20000
City_of_Buena_Vista	20000	1.58	2.47	0.72	20000	20000	20000	20000
City_of_Charlottesville		20000	20000	20000	0.73	1.56	1.22	20000	20000
City_of_Chesapeake	20000	20000	20000	20000	20000	1.87	2.18	0.67	
City_of_Clifton_Forge		20000	1.92	20000	1.08	20000	20000	20000	20000
City_of_Colonial_Heights		20000	20000	20000	20000	20000	0.43	1.37	1.47
City_of_Covington	20000	1.88	20000	1.26	20000	20000	20000	20000	

City_of_Emporia	20000	20000	1.32	20000	20000	1.2	2.03	1.27	
City_of_Fairfax	20000	20000	20000	20000	0.71	20000	2.02	20000	
City_of_Falls_Church	20000	20000	20000	20000	0.93	20000	2.05	20000	
City_of_Franklin	20000	20000	1.93	20000	20000	20000	20000	0.58	
City_of_Fredericksburg		20000	20000	20000	2.18	0.96	1.03	1.08	20000
City_of_Hampton	20000	20000	20000	20000	20000	1.3	1.62	0.82	
City_of_Harrisonburg	20000	20000	20000	0.61	1.65	20000	20000	20000	
City_of_Lexington	20000	1.57	20000	0.66	20000	20000	20000	20000	
City_of_Lynchburg	20000	20000	1.8	20000	20000	2.26	20000	20000	
City_of_Manassas	20000	20000	20000	20000	0.58	1.75	1.95	20000	
City_of_Manassas_Park		20000	20000	20000	20000	0.78	1.75	1.95	20000
City_of_Newport_News		20000	20000	20000	20000	20000	1.32	1.63	0.65
City_of_Norfolk	20000	20000	20000	20000	20000	1.65	1.97	0.55	
City_of_Norton	1	20000	20000	20000	20000	20000	20000	20000	
City_of_Petersburg	20000	20000	1.45	20000	20000	0.45	1.38	1.42	
City_of_Poquoson	20000	20000	20000	20000	20000	1.23	1.43	0.98	
City_of_Portsmouth	20000	20000	20000	20000	20000	1.68	2	0.5	
City_of_Radford	1.47	0.2	20000	20000	20000	20000	20000	20000	
City_of_Richmond	20000	20000	20000	0	0.98	1.85	20000	20000	
City_of_Roanoke	20000	0.9	2.75	1.47	20000	20000	20000	20000	
City_of_Salem	20000	0.75	2.91	1.48	20000	20000	20000	20000	
City_of_Staunton	20000	20000	20000	0	2.06	20000	20000	20000	
City_of_Suffolk	20000	20000	20000	20000	20000	1.83	2.23	0	
City_of_Virginia_Beach		20000	20000	20000	20000	20000	1.87	2.17	0.85
City_of_Waynesboro	20000	20000	20000	0.36	20000	20000	20000	20000	
City_of_Williamsburg		20000	20000	20000	20000	20000	0.88	1.42	1.27
City_of_Winchester	20000	20000	20000	1.65	1.05	20000	20000	20000	
Clarke_County	20000	20000	20000	0.72	1.03	20000	20000	20000	
Craig_County	20000	1.13	20000	1.73	20000	20000	20000	20000	
Culpeper_County	20000	20000	20000	1.53	0.6	1.75	1.93	20000	
Cumberland_County	20000	20000	1.55	1.72	2.43	1.13	2.03	20000	
Dickenson_County	1.35	20000	20000	20000	20000	20000	20000	20000	
Dinwiddie_County	20000	20000	114	20000	20000	0.75	1.68	1.68	
Essex_County	20000	20000	20000	20000	1.95	1	0	2.25	
Fairfax_County	20000	20000	20000	20000	0.71	1.82	2.02	20000	
Fauquier_County	20000	20000	20000	1.98	0	20000	1.96	20000	
Floyd_County	1.9	0.67	20000	20000	20000	20000	20000	20000	
Fluvanna_County	20000	20000	2.48	1	1.65	1.1	1.88	20000	
Franklin_County	20000	1.42	2.67	1.93	20000	20000	20000	20000	
Frederick_County	20000	20000	20000	1.55	1.05	20000	20000	20000	
Giles_County	1.77	0.45	20000	20000	20000	20000	20000	20000	
Gloucester_County	20000	20000	20000	20000	20000	1.13	0.85	1.43	
Goochland_County	20000	20000	1.88	1.37	1.93	0.63	1.42	20000	
Grayson_County	1.38	1.16	20000	20000	20000	20000	20000	20000	
Greene_County	20000	20000	20000	1.17	1.21	1.57	2.38	20000	
Greensville_County	20000	20000	1.33	20000	20000	1.25	20000	1.27	
Halifax_County	20000	20000	0.55	20000	20000	20000	20000	20000	
Hanover_County	20000	20000	20000	1.87	1.58	0.45	0.87	2.13	
Henrico_County	20000	20000	1.88	20000	1.75	0	20000	1.85	
Henry_County	20000	1.72	1.75	20000	20000	20000	20000	20000	
Highland_County	20000	20000	20000	1.15	20000	20000	20000	20000	
Hopewell_County	20000	20000	20000	20000	20000	0.5	1.25	20000	
Isle_of_Wright_County		20000	20000	20000	20000	20000	1.58	2.12	0.6
James_City_County	20000	20000	20000	20000	20000	0.88	1.42	1.27	
King_and_Queen_County		20000	20000	20000	20000	2.25	0.97	0.42	2.1
King_George_County	20000	20000	20000	20000	1.33	1.22	0.73	20000	
King_William_County		20000	20000	20000	20000	2.01	0.75	0.55	2

Lancaster_County	20000	20000	20000	20000	20000	1.58	0.67	2.3	
Lee_County	1.6	20000	20000	20000	20000	20000	20000	20000	
Loudoun_County	20000	20000	20000	2.36	0.83	20000	2.5	20000	
Louisa_County	20000	20000	20000	20000	1.32	1.05	1.85	20000	
Lunenburg_County	20000	20000	0.77	20000	20000	1.55	20000	20000	
Madison_County	20000	20000	20000	1.16	0.92	1.61	2.18	20000	
Mathews_County	20000	20000	20000	20000	20000	1.5	1.13	1.81	
Mecklenburg_County	20000	20000	0.23	20000	20000	1.65	20000	20000	
Middlesex_County	20000	20000	20000	20000	20000	1.02	0.55	1.72	
Montgomery_County	1.58	0.35	20000	20000	20000	20000	20000	20000	
Nelson_County	20000	20000	2.16	0.73	2.11	2.1	20000	20000	
New_Kent_County	20000	20000	20000	20000	20000	0.55	1.13	1.58	
Northhampton_County		20000	20000	20000	20000	20000	20000	20000	1.58
Northumberland_County		20000	20000	20000	20000	20000	1.57	0.57	2.6
Nottoway_County	20000	20000	1.32	2.35	20000	1.27	2.2	2.32	
Orange_County	20000	20000	20000	1.26	1	1.35	1.83	20000	
Page_County	20000	20000	20000	1.06	1.05	20000	20000	20000	
Patrick_County	20000	1.25	20000	20000	20000	20000	20000	20000	
Pittsylvania_County	20000	2.3	1.37	20000	20000	20000	20000	20000	
Powhatan_County	20000	20000	1.78	1.66	2.25	0.75	1.7	20000	
Prince_Edward_County		20000	20000	1.17	1.86	20000	1.33	20000	20000
Prince_George_County		20000	20000	2.27	20000	20000	0.45	1.38	1.88
Prince_William_County		20000	20000	20000	20000	0.58	1.75	1.95	20000
Pulaski_County	1.28	0.15	20000	20000	20000	20000	20000	20000	
Rappahannock_County		20000	20000	20000	1.56	0.5	2.2	2.48	20000
Richmond_County	20000	20000	20000	20000	20000	1.15	0.08	2.4	
Roanoke_County	20000	0.75	2.91	1.42	20000	20000	20000	20000	
Rockbridge_County	20000	1.57	2.63	0.58	20000	20000	20000	20000	
Rockingham_County	20000	20000	20000	0.52	1.65	20000	20000	20000	
Russell_County	0.46	1.8	20000	20000	20000	20000	20000	20000	
Scott_County	0.87	20000	20000	20000	20000	20000	20000	20000	
Shenandoah_County	20000	20000	20000	1	1.03	20000	20000	20000	
Smyth_County	0.5	0.88	20000	20000	20000	20000	20000	20000	
Southhampton_County		20000	20000	1.81	20000	20000	1.25	2.08	0.71
Spotsylvania_County	20000	20000	20000	2.05	1.13	1.03	1.22	20000	
Stafford_County	20000	20000	20000	20000	0.96	1.08	1.28	20000	
Surry_County	20000	20000	20000	20000	20000	1.2	1.95	1	
Sussex_County	20000	20000	1.57	20000	20000	20000	20000	1.2	
Tazewell_County	1.15	1.43	20000	20000	20000	20000	20000	20000	
Warren_County	20000	20000	20000	1.5	0.75	20000	20000	20000	
Washington_County	0	1.33	20000	20000	20000	20000	20000	20000	
Westmoreland_County		20000	20000	20000	20000	1.87	1.42	0.4	20000
Wise_County	1.06	20000	20000	20000	20000	20000	20000	20000	
Wythe_County	0.9	0.5	20000	20000	20000	20000	20000	20000	
York_County	20000	20000	20000	20000	20000	1.12	1.12	1.15;	

param A : ES Stormwater Nutmgmt CDC WFC :=
Abingdon 1920 3840 960 1920 1920
Clarksville 1920 1920 1920 1920 960
Christiansburg 1920 3840 1920 1920 960
Richmond 5760 3840 1920 1920 3840
Suffolk 3840 3840 5760 1920 1920
Tappahannock 3840 5760 3840 1920 1920
Warrenton 1920 3840 3840 1920 1920
Staunton 3840 3840 9600 1920 1920;

APPENDIX C

Appendix C.1 Solution keeping SWCDs intact

Regional Office	Localities in New Assignment	Current Assignment	Comparison with existing solution
Abingdon	Buchanan_County	Buchanan County	**No changes in localities assigned**
	City_of_Bristol	City of Bristol	
	City_of_Norton	City_of_Norton	
	Dickenson_County	Dickenson County	
	Lee_County	Lee County	
	Russell_County	Russell County	
	Scott_County	Scott County	
	Smyth_County	Smyth County	
	Tazewell_County	Tazewell County	
	Washington_County	Washington County	
	Wise_County	Wise County	
Christiansburg	Bland_County	Bland County	**7 localities have been added**
	Botetourt_County	Carroll County	
	Carroll_County	City_of_Radford	
	City_of_Radford	Floyd County	
	City_of_Roanoke	Giles County	
	City_of_Salem	Grayson County	
	Craig_County	Montgomery County	
	Floyd_County	Patrick County	
	Franklin_County	Pulaski County	
	Giles_County	Wythe County	
	Grayson_County		
	Henry_County		
	Montgomery_County		
	Patrick_County		
	Pittsylvania_County		
	Pulaski_County		
	Roanoke_County		
	Wythe_County		
Staunton	Alleghany_County	Alleghany County	**2 localities have been addeed.**

	Augusta_County	Augusta County	
	Bath_County	Bath County	
	Bedford_County	Botetourt County	
	City_of_Bedford	City of Buena Vista	
	City_of_Buena_Vista	City of Covington	
	City_of_Clifton_Forge	City of Harrisonburg	
	City_of_Covington	City of Lexington	
	City_of_Harrisonburg	City of Staunton	
	City_of_Lexington	City of Waynesboro	
	City_of_Staunton	City of Winchester	
	City_of_Waynesboro	City_of_Clifton_Forge	
	Highland_County	Clarke County	
	Page_County	Craig County	
	Rockbridge_County	Frederick County	
	Rockingham_County	Highland County	
		Page County	
		Rockbridge County	
		Rockingham County	
		Shenandoah County	
		Warren County	
Clarksville	Amherst_County	Bedford County	**6 localities have been added**
	Appomattox_County	Brunswick County	
	Brunswick_County	Charlotte County	
	Campbell_County	City of Bedford	
	Charlotte_County	City of Roanoke	
	City_of_Lynchburg	City_of_Salem	
	Halifax_County	Franklin County	
	Lunenburg_County	Halifax County	
	Mecklenburg_County	Henry County	
	Nottoway_County	Lunenburg County	
	Prince_Edward_County	Mecklenburg County	
		Pittsylvania County	
		Roanoke County	
Warrenton	Arlington_County	Arlington_County	**10 localities have been added**
	City_of_Alexandria	City_of_Alexandria	
	City_of_Fairfax	City_of_Fairfax	

	City_of_Falls_Church	City_of_Falls_Church	
	City_of_Manassas	City_of_Manassas	
	City_of_Winchester	City_of_Manassas_Park	
	Clarke_County	Fairfax County	
	Culpeper_County	Fauquier County	
	Fairfax_County	Loudoun County	
	Fauquier_County	Prince William County	
	Frederick_County		
	Greene_County		
	Loudoun_County		
	Madison_County		
	Orange_County		
	Prince_William_County		
	Rappahannock_County		
	Shenandoah_County		
	Warren_County		
Richmond	Albemarle_County	Albemarle County	**9 localities have been added**
	Buckingham_County	Amelia County	
	Charles_City_County	Amherst County	
	Chesterfield_County	Appomattox County	
	City_of_Charlottesville	Buckingham County	
	City_of_Manassas_Park	Campbell County	
	City_of_Petersburg	Chesterfield County	
	City_of_Poquoson	City of Charlottesville	
	City_of_Richmond	City of Lynchburg	
	City_of_Williamsburg	City_of_Colonial_Heights	
	Cumberland_County	City_of_Richmond	
	Dinwiddie_County	Cumberland County	
	Fluvanna_County	Fluvanna County	
	Henrico_County	Goochland County	
	Hopewell_County	Henrico County	
	James_City_County	Hopewell_County	
	Louisa_County	Louisa County	
	Nelson_County	Nelson County	
	New_Kent_County	Nottoway County	
	Prince_George_County	Powhatan County	
	York_County	Prince Edward County	

		Prince George County	
Tappahannock	Caroline_County	Caroline County	**4 localities have been added**
	City_of_Colonial_Heights	Charles City County	
	City_of_Fredericksburg	City of Williamsburg	
	City_of_Hampton	City_of_Fredericksburg	
	Essex_County	City_of_Poquoson	
	Gloucester_County	City_of_Williamsburg	
	Goochland_County	Culpeper_County	
	Hanover_County	Essex County	
	King_and_Queen_County	Gloucester County	
	King_George_County	Greene_County	
	King_William_County	Hanover County	
	Lancaster_County	James City County	
	Mathews_County	King and Queen County	
	Middlesex_County	King William County	
	Northumberland_County	King_George_County	
	Powhatan_County	Lancaster County	
	Richmond_County	Mathews County	
	Spotsylvania_County	Middlesex County	
	Stafford_County	New Kent County	
	Westmoreland_County	Northumberland County	
		Orange_County	
		Rappahannock_County	
		Richmond County	
		Spotsylvania County	
		Stafford_County	
		Westmoreland County	
		York County	
Suffolk	Accomack_County	Accomack County	**No changes to localities assigned**
	City_of_Chesapeake	City of Chesapeake	
	City_of_Emporia	City of Petersburg	
	City_of_Franklin	City of Suffolk	
	City_of_Newport_News	City of Virginia Beach	
	City_of_Norfolk	City_of_Emporia	
	City_of_Portsmouth	City_of_Franklin	
	City_of_Suffolk	City_of_Hampton	

	City_of_Virginia_Beach	City_of_Newport_News	
	Greensville_County	City_of_Norfolk	
	Isle_of_Wright_County	City_of_Portsmouth	
	Northhampton_County	Dinwiddie County	
	Southhampton_County	Greensville County	
	Surry_County	Isle of Wright County	
	Sussex_County	Northhampton County	
		Southhampten County	
		Surry County	
		Sussex County	
		In TOTAL	**38 localities have been reassigned**

Appendix C.2 Solutions relaxing constraint on SWCDs

Regional Office	**Localities in New Assignment**	**Current Assignment**	**Comparison with existing solution**
Abingdon	Buchanan_County	Buchanan County	**No changes in localities assigned**
	City_of_Bristol	City of Bristol	
	City_of_Norton	City_of_Norton	
	Dickenson_County	Dickenson County	
	Lee_County	Lee County	
	Russell_County	Russell County	
	Scott_County	Scott County	
	Smyth_County	Smyth County	
	Tazewell_County	Tazewell County	
	Washington_County	Washington County	
	Wise_County	Wise County	
Christiansburg	Bedford_County	Bland County	**8 localities have been added**
	Bland_County	Carroll County	
	Botetourt_County	City_of_Radford	
	Carroll_County	Floyd County	
	City_of_Radford	Giles County	
	City_of_Roanoke	Grayson County	
	City_of_Salem	Montgomery County	

	Craig_County	Patrick County	
	Floyd_County	Pulaski County	
	Franklin_County	Wythe County	
	Giles_County		
	Grayson_County		
	Henry_County		
	Montgomery_County		
	Patrick_County		
	Pulaski_County		
	Roanoke_County		
	Wythe_County		
Staunton	Albemarle_County	Alleghany County	**7 localities have been addeed.**
	Alleghany_County	Augusta County	
	Amherst_County	Bath County	
	Augusta_County	Botetourt County	
	Bath_County	City of Buena Vista	
	Buckingham_County	City of Covington	
	City_of_Buena_Vista	City of Harrisonburg	
	City_of_Charlottesville	City of Lexington	
	City_of_Clifton_Forge	City of Staunton	
	City_of_Covington	City of Waynesboro	
	City_of_Harrisonburg	City of Winchester	
	City_of_Lexington	City_of_Clifton_Forge	
	City_of_Staunton	Clarke County	
	City_of_Waynesboro	Craig County	
	Greene_County	Frederick County	
	Highland_County	Highland County	
	Madison_County	Page County	
	Nelson_County	Rockbridge County	
	Rockbridge_County	Rockingham County	
	Rockingham_County	Shenandoah County	
		Warren County	
Clarksville	Appomattox_County	Bedford County	**5 localities have been added**
	Brunswick_County	Brunswick County	
	Campbell_County	Charlotte County	
	Charlotte_County	City of Bedford	
	City_of_Bedford	City of Roanoke	
	City_of_Lynchburg	City_of_Salem	

	Greensville_County	Franklin County	
	Halifax_County	Halifax County	
	Lunenburg_County	Henry County	
	Mecklenburg_County	Lunenburg County	
	Pittsylvania_County	Mecklenburg County	
	Prince_Edward_County	Pittsylvania County	
		Roanoke County	
Warrenton	Arlington_County	Arlington_County	**9 localities have been added**
	City_of_Alexandria	City_of_Alexandria	
	City_of_Fairfax	City_of_Fairfax	
	City_of_Falls_Church	City_of_Falls_Church	
	City_of_Manassas	City_of_Manassas	
	City_of_Manassas_Park	City_of_Manassas_Park	
	City_of_Winchester	Fairfax County	
	Clarke_County	Fauquier County	
	Culpeper_County	Loudoun County	
	Fairfax_County	Prince William County	
	Fauquier_County		
	Frederick_County		
	Loudoun_County		
	Orange_County		
	Page_County		
	Prince_William_County		
	Rappahannock_County		
	Shenandoah_County		
	Warren_County		
Richmond	Amelia_County	Albemarle County	**10 localities have been added**
	Charles_City_County	Amelia County	
	Chesterfield_County	Amherst County	
	City_of_Colonial_Heights	Appomattox County	
	City_of_Emporia	Buckingham County	
	City_of_Petersburg	Campbell County	
	City_of_Poquoson	Chesterfield County	
	City_of_Richmond	City of Charlottesville	
	City_of_Williamsburg	City of Lynchburg	
	Cumberland_County	City_of_Colonial_Heights	

	Dinwiddie_County	City_of_Richmond	
	Fluvanna_County	Cumberland County	
	Goochland_County	Fluvanna County	
	Hanover_County	Goochland County	
	Henrico_County	Henrico County	
	Hopewell_County	Hopewell_County	
	James_City_County	Louisa County	
	Louisa_County	Nelson County	
	New_Kent_County	Nottoway County	
	Nottoway_County	Powhatan County	
	Powhatan_County	Prince Edward County	
	Prince_George_County	Prince George County	
	Stafford_County		
Tappahannock	Caroline_County	Caroline County	**No changes in localities assigned**
	City_of_Fredericksburg	Charles City County	
	Essex_County	City of Williamsburg	
	Gloucester_County	City_of_Fredericksburg	
	King_and_Queen_County	City_of_Poquoson	
	King_George_County	City_of_Williamsburg	
	King_William_County	Culpeper_County	
	Lancaster_County	Essex County	
	Mathews_County	Gloucester County	
	Middlesex_County	Greene_County	
	Northumberland_County	Hanover County	
	Richmond_County	James City County	
	Spotsylvania_County	King and Queen County	
	Westmoreland_County	King William County	
	York_County	King_George_County	
		Lancaster County	
		Mathews County	
		Middlesex County	
		New Kent County	
		Northumberland County	
		Orange_County	
		Rappahannock_County	
		Richmond County	
		Spotsylvania County	

		Stafford_County	
		Westmoreland County	
		York County	
Suffolk	Accomack_County	Accomack County	**No changes in localities assigned**
	City_of_Chesapeake	City of Chesapeake	
	City_of_Franklin	City of Petersburg	
	City_of_Hampton	City of Suffolk	
	City_of_Newport_News	City of Virginia Beach	
	City_of_Norfolk	City_of_Emporia	
	City_of_Portsmouth	City_of_Franklin	
	City_of_Suffolk	City_of_Hampton	
	City_of_Virginia_Beach	City_of_Newport_News	
	Isle_of_Wright_County	City_of_Norfolk	
	Northhampton_County	City_of_Portsmouth	
	Southhampton_County	Dinwiddie County	
	Surry_County	Greensville County	
	Sussex_County	Isle of Wright County	
		Northhampton County	
		Southhampten County	
		Surry County	
		Sussex County	
		IN TOTAL	**39 localities have been reassigned**

Appendix C.3 Cost comparisons between solutions

	COST COMPARISONS			SAVINGS WRT CURRENT ASSIGNMENT	
Total Travel time cost	**Current Assignment**	**With SWCD**	**Without SWCD**	**Savings wrt SWCD**	**Savings w/o SWCD**
Abingdon	$24,433.20	$24,433.20	$24,433.20		
Clarksville	$37,130.10	$27,626.00	$26,376.00		
Christiansburg	$11,007.40	$30,130.90	$28,884.40		
Richmond	$66,646.30	$63,446.20	$53,605.80		
Suffolk	$89,050.50	$73,164.50	$70,004.00		
Tappahannock	$58,847.90	$31,050.20	$19,571.20		
Warrenton	$30,555.70	$42,667.60	$43,967.60		
Staunton	$48,891.40	$39,932.90	$45,812.50		
Total	**$366,562.50**	**$332,451.50**	**$312,654.70**	**$34,111.00**	**$53,907.80**

Total Mileage Cost	**Current Assignment**	**With SWCD**	**Without SWCD**
Abindon	$26,855.00	$26,855.00	$26,855.00
Clarksville	$38,710.60	$30,554.60	$28,615.90
Christiansburg	$12,600.90	$35,654.60	$34,454.20
Richmond	$76,144.80	$75,424.10	$62,418.30
Suffolk	$76,592.90	$60,781.50	$57,507.80
Tappahannock	$64,084.40	$33,718.20	$21,366.50
Warrenton	$28,486.00	$41,633.30	$42,440.60
Staunton	$59,892.30	$45,511.80	$52,634.80
Total	**$383,366.90**	**$350,133.10**	**$326,293.10**

$33,233.80 **$57,073.80**

Total Cost	Current Assignment	With SWCD	Without SWCD		
Abindon	$51,288.20	$51,288.20	$51,288.20		
Clarksville	$75,840.70	$58,180.60	$54,991.80		
Christiansburg	$23,608.30	$65,785.50	$63,338.60		
Richmond	$142,791.00	$138,870.00	$116,024.00		
Suffolk	$165,643.00	$133,946.00	$127,512.00		
Tappahannock	$122,932.00	$64,768.50	$40,937.80		
Warrenton	$59,041.70	$84,300.80	$86,408.10		
Staunton	$108,784.00	$85,444.70	$98,447.30		
Total	**$749,928.90**	**$682,584.30**	**$638,947.80**	**$67,344.60**	**$110,981.10**
Total Travel time	**Current Assignment**	**With SWCD**	**Without SWCD**		
Abingdon	939.74	939.74	939.74		
Clarksville	1,428.08	1,062.54	1,014.46		
Christiansburg	423.36	1,158.88	1,110.94		
Richmond	2,563.32	2,440.24	2,061.76		
Suffolk	3,425.02	2,814.02	2,692.46		
Tappahannock	2,263.38	1,194.24	752.74		
Warrenton	1,175.22	1,641.06	1,691.06		
Staunton	1,880.44	1,535.88	1,762.02		
Total	**14,098.56**	**12,786.60**	**12,025.18**	**1,311.96**	**2,073.38**
Total Mileage	**Current Assignment**	**With SWCD**	**Without SWCD**		
Abindon	45,906.00	45,906.00	45,906.00		
Clarksville	66,172.00	52,230.00	48,916.00		
Christiansburg	21,540.00	60,948.00	58,896.00		
Richmond	130,162.00	128,930.00	106,698.00		
Suffolk	130,928.00	103,900.00	98,304.00		
Tappahannock	109,546.00	57,638.00	36,524.00		
Warrenton	48,694.00	71,168.00	72,548.00		
Staunton	102,380.00	77,798.00	89,974.00		
Total	**655,328.00**	**598,518.00**	**557,766.00**	**56,810.00**	**97,562.00**

APPENDIX D

Appendix D.1 Final Assignment

Abingdon	Christiansburg
Buchanan_County	Botetourt_County
City_of_Bristol	City_of_Radford
City_of_Norton	City_of_Roanoke
Dickenson_County	City_of_Salem
Lee_County	Craig_County
Russell_County	Floyd_County
Scott_County	Franklin_County
Smyth_County	Giles_County
Tazewell_County	Henry_County
Washington_County	Montgomerty_County
Wise_County	Patrick_County
Bland_County	Pulaski_County
Carroll_County	Roanoke_County
City_of_Galax	
Grayson_County	
Wythe_County	

Warrenton	Richmond
Arlington_County	Amelia_County
City_of_Alexandria	Buckingham_County
City_of_Fairfax	Charles_City_County
City_of_Falls_Church	Chesterfield_County
City_of_Manassas	City_of_Colonial_Heights
City_of_Manassas_Park	City_of_Richmond
City_of_Winchester	Cumberland_County
Clarke_County	Dinwiddie_County
Culpepper_County	Fluvanna_County
Fairfax_County	Goochland_County
Fauquier_County	Hanover_County
Frederick_County	Henrico_County
Greene_County	Hopewell_County
Loudoun_County	Louisa_County
Madison_County	New_Kent_County
Orange_County	Nottoway_County
Prince_William_County	Powhatan_County
Rappahannock_County	Prince_George_County
Warren_County	

Staunton	Clarksville
Albemarle_County	Amherst_County
Alleghany_County	Appomattox_County
Augusta_County	Bedford_County
Bath_County	Brunswick_County
City_of_Buena_Vista	Campbell_County
City_of_Charlottesville	Charlotte_County
City_of_Clifton_Forge	City_of_Bedford
City_of_Covington	City_of_Lynchburg
City_of_Harrisonburg	Halifax_County
City_of_Lexington	Lunenburg_County
City_of_Staunton	Mecklenburg_County
City_of_Waynesboro	Pittsylvania_County
Highland_County	Prince_Edward_County
Nelson_County	
Page_County	
Rockbridge_County	
Rockingham_County	
Shenandoah_County	

Tappahannock	Suffolk
Caroline_County	Accomack_County
City_of_Fredericksburg	City_of_Cheaspeake
City_of_Williamsburg	City_of_Emporia
Essex_County	City_of_Franklin
Gloucester_County	City_of_Hampton
James_City_County	City_of_Newport_News
King_and_Queen_County	City_of_Norfolk
King_George_County	City_of_Petersburg
King_William_County	City_of_Portsmouth
Lancaster_County	City_of_Suffolk
Mathews_County	City_of_Virginia_Beach
Middlesex_County	Greensville_County
Northumberland_County	Isle_of_Wright_County
Richmond_County	Northhampton_County
Spotsylvania_County	Southhampton_County
Stafford_County	Surry_County
Westmoreland_County	Sussex_County
York_County	City_of_Poquoson

Appendix D.2 Cost Analysis of final assignment

The table below shows the costs for each regional office for the final assignments decided by DCR. Their assignment was $24,582 more than the assignment proposed by us (without the restriction on SWCDs).

	Abingdon	Clarksville	Christiansburg	Richmond	Suffolk	Tappahannock	Warrenton	Staunton	TOTALS
Travel Cost	$33,555.10	$31,566.10	$17,611.40	$43,099.20	$79,593.80	$34,653.30	$41,456.50	$44,323.20	**$325,858.60**
Mileage Cost	$38,548.00	$33,879.70	$21,081.10	$47,534.80	$66,830.40	$38,443.90	$39,742.60	$51,611.00	**$337,671.50**
Total Cost	$72,103.10	$65,445.80	$38,692.40	$90,633.90	$146,424.00	$73,097.20	$81,199.00	$95,934.30	**$663,529.70**

	Abingdon	Clarksville	Christiansburg	Richmond	Suffolk	Tappahannock	Warrenton	Staunton
ES	-639.68	-1064.24	-1226.62	-3550.86	103.52	-1708.82	-214.32	-1577.20
Stormwater	-1120.58	-60.20	-2752.08	-743.90	240.64	-3891.76	-1098.54	48.42
Nut. Mgmt	-616.6	-375.64	-501.70	140.14	-314.98	-1280.52	-1862.94	-1954.32
CDC	-927.24	-175.64	-706.72	-735.68	-116.68	-758.10	-712.36	-721.56
WFC	-946.32	-691.20	-215.52	-3370.04	194.80	-563.98	-40.36	-1432.60

The table also shows that their final assignment was infeasible for our model. The shaded numbers indicate that the regional offices have requirement greater than available resource for the corresponding program areas.