ORNL/TM-2014/300

Population Sensitivity Evaluation of Two Candidate Locations for Possible Small Modular Reactor Siting

R. J. Belles
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Reactor and Nuclear Systems Division
Computational Sciences and Engineering Division

POPULATION SENSITIVITY EVALUATION OF TWO CANDIDATE LOCATIONS FOR POSSIBLE SMALL MODULAR REACTOR SITING

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ACRONYMS

B&W	Babcock and Wilcox
DOE	US Department of Energy
Dominion	Virginia Electric and Power Company
EPRI	Electric Power Research Institute
EPZ	emergency planning zone
GIS	geographic information systems
iPWR	integral pressurized-water reactor
MW(e)	megawatt electrical
NASA	National Aeronautics and Space Administration
NE	(DOE) Office of Nuclear Energy
NRC	US Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
OR-SAGE	Oak Ridge Siting Analysis for power Generation Expansion
PWR	pressurized-water reactor
SSEC	site selection and evaluation criteria
SMR	small modular reactor
USGS	US Geological Survey
VSEC	Virginia-Hampton Roads Small modular reactor Energy Development Council
ZIP Code	Postal Zone Improvement Plan Code

EXECUTIVE SUMMARY

Beginning in late 2008, Oak Ridge National Laboratory (ORNL) responded to ongoing internal and external studies addressing key questions related to our national electrical energy supply. This effort has led to the development and refinement of Oak Ridge Siting Analysis for power Generation Expansion (OR-SAGE), a tool to support power plant siting evaluations. The OR-SAGE tool employs an array of geographic information systems (GIS) data sources at ORNL to identify candidate areas for a power generation technology application.

The overall objective of this research project is to use the OR-SAGE tool to support the US Department of Energy (DOE) Office of Nuclear Energy (NE) in evaluating future electrical generation deployment options for small modular reactors (SMRs) in areas with significant energy demand from the federal sector. Deployment of SMRs in zones with high federal energy use can provide a means of meeting federal clean energy goals.

The Task 1 report* documented the identification of US locations to possibly site new SMR nuclear power plants in areas where the concentration and electricity use by federal government agencies is high and forecasted to grow in the next 10 years. "Federal agencies" include military and other agencies (e.g., Homeland Security, DOE, Federal Bureau of Investigation, and Social Security Administration) that have missions of national critical importance. Using publically available data, federal energy usage was catalogued by the first two digits of the Postal Zone Improvement Plan (ZIP) Code and by the full ZIP Code. The combined federal energy data sorted by the first two digits of the ZIP Code is shown in Fig. ES-1. The orange, dark blue, and red colored areas in Fig. ES-1 have higher federal energy consumption. For clarity, the only dark blue areas are in Virginia, North Carolina, and Washington. Note that eastern Washington, which is dark blue, shares the same two-digit ZIP Code area (99) as all of Alaska. The dark blue color in eastern Washington is a result of the power demand in Alaska.

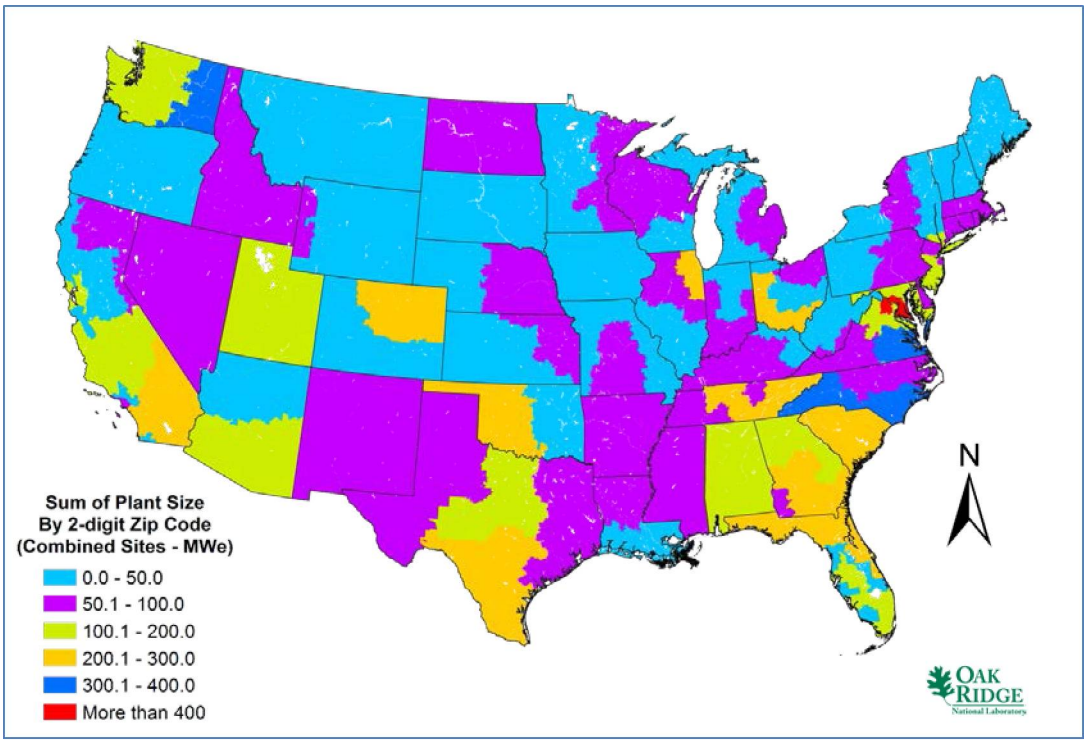

Fig. ES-1. Combined federal energy consumption by two-digit ZIP Code area.

* References to previous task reports are included in the main body of the report.

Federal sites depicted by the full ZIP Code are represented by colored dots in Fig. ES-2. The size and the color of each dot indicate the average annual energy consumption within a specific ZIP Code for FY 2009–FY 2012. Based on available data, thirteen federal energy clusters were identified and eight were selected as areas with significant energy consumption to provide favorable opportunities for SMR siting. These clusters are discussed in detail in the Task 1 report. The Hampton Roads, Virginia, area was identified as being among the largest federal energy clusters. These federal power clusters were identified based upon power usage data, geographical concentration (collocation) of federal agencies, or operation of large federal data centers.

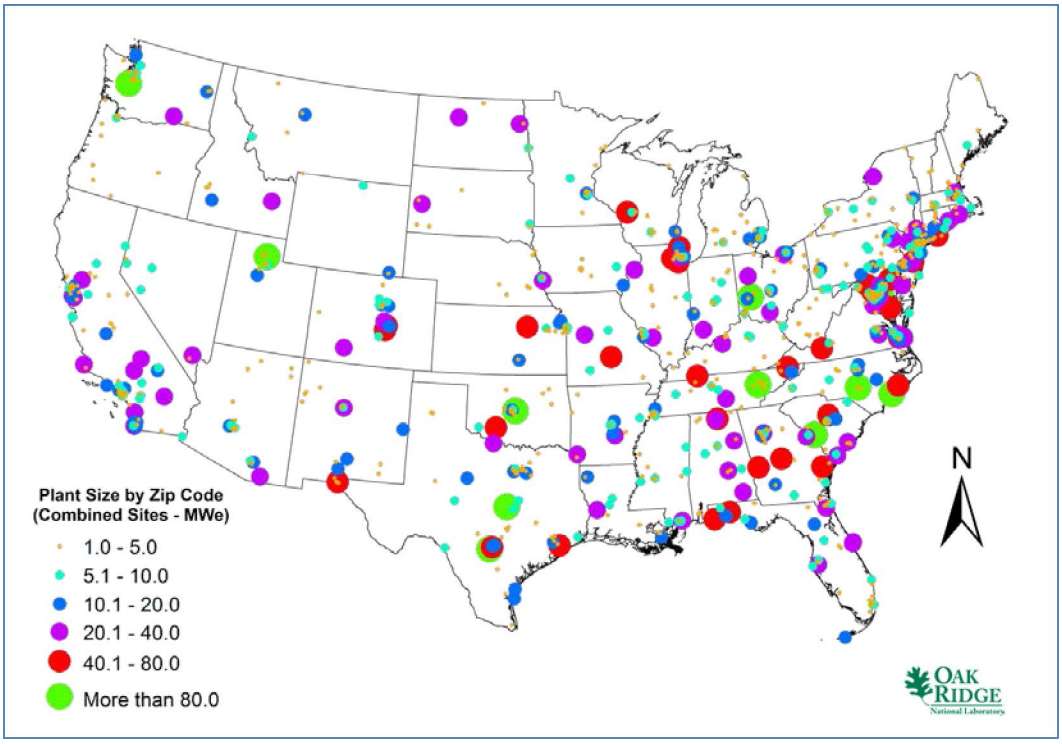

Fig. ES-2. Energy consumption at reported federal facilities.

In Task 2, eleven potential sites in the Hampton Roads, Virginia, area were identified for evaluation by the Virginia-Hampton Roads Small modular reactor Energy Development Council (VSEC). The proposed sites are represented as blue dots and labeled on the regional map below in Fig. ES-3. The sites were evaluated using the OR-SAGE tool based on previously developed screening criteria and the application of spatial modeling and GIS. However, the population screening criteria were not applied to the site evaluations because the standard OR-SAGE population avoidance layer calculation impacts large areas of land close to population centers. This would have negated most of the potential Hampton Roads area sites from further consideration and the Task 3 analysis will show the sensitivity of the population calculation using more detailed population tools. For reference purposes, a generalized SMR plant parameter envelope for the Babcock and Wilcox (B&W) Generation dual unit mPower integral design (360 MW(e)) was used for all site evaluations. The mPower design nominally requires a 40-acre footprint.

Based on the analyses of Task 2, each of the eleven individual sites was binned into one of three categories:

1. Exclusive of population, the site meets multiple conventional standards for consideration of siting an SMR at the proposed location. There are no current or near-term foreseeable SMR siting issues that should preclude this site from further SMR siting consideration.

2. Exclusive of population, the site meets multiple conventional standards in the near term for consideration of siting an SMR at the proposed location, but there may be longer-term issues that could preclude this site from further SMR siting consideration. For example, the site may be heavily developed with little room for expansion necessary to site an SMR.
3. The site is not a likely candidate for consideration of siting an SMR. Numerous siting criteria are not met, or other parameters exist that could make it difficult to site an SMR.

Fig. ES-3. Regional view of evaluated Hampton Roads sites.

Table 2 in the main body of this report summarizes the Task 2 results. Nine of the eleven sites demonstrated reasonable potential for further consideration for placement of an SMR. Five of these nine sites were judged to be more favorable. Of these, the Surry Nuclear Power Station, Camp Peary, and the Yorktown Naval Weapons Station (Naval Weapons Annex) stand out based upon the OR-SAGE screening criteria and apparent space available. Evaluations of current grid infrastructure, potential for micro-grid infrastructure, or other factors of potential interest to VSEC (that are not part of the standard OR-SAGE criteria) were not part of the Task 2 site reviews. Therefore, other sites could be judged more favorably based on additional screening parameters.

A data package and analysis for each site in the sample set was prepared in Task 2, and the results were reported to DOE-NE by letter report. A brief summary of these evaluations is available in Appendix A of this report. The complete set of evaluations is available in the Task 2 letter report.

Task 3 of the project evaluates two of those individual sites for sensitivity to population density. Sensitivity to population density is a significant factor of interest in the potential for siting new SMRs and possibly backfitting SMRs into older coal plant facilities. Initially, VSEC was to select the two sites of interest, but after VSEC withdrew from the project, ORNL staff members selected two sites for further

study. Based on the Task 2 analyses and the initial evaluation of population density averaged over a radial distance out to 10 miles in Task 3, the Surry Power Station, Camp Peary, and the Yorktown Weapons Station clearly have excellent potential for hosting an mPower plant to support federal power needs. All three of these sites have significant space, and none of these sites have significant population issues evaluated out to a distance of 10 miles. Therefore, further evaluation of population density around these three sites did not appear to be overly informative.

Six additional Task 2 sites were evaluated as favorable for siting an mPower plant with either no or minimal siting issues. Again, the Task 2 evaluation did not consider population density as a factor. The initial evaluation of population density in Task 3 indicated that these six sites would be of further interest for a more in-depth look at population density surrounding the sites. These six sites are also closer to the centroid of the urban population in the Hampton Roads area (see Fig. 4 in the main body of the report).

Regional ambient population density analyses based on the US Nuclear Regulatory Commission (NRC) Regulatory Guide 4.7 approach were conducted at distances of 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, and 10 miles. These plots are shown in Sect. 2.1. Based on this initial screen and the Task 2 results, the Yorktown Power Station and Fort Story were selected for further detailed population density evaluation. Localized LandScan™ plots of these two facilities were evaluated. The ORNL LandScan™ database is a highly sophisticated population database that provides high-resolution global population distribution data representing day, night, or ambient population (averaged to account for seasonal and daily variations).

As shown in Fig. ES-4, the area in the immediate vicinity of the Yorktown Power Station is lightly populated. The area is industrialized and contains suburban population densities compared with the more urban densities observed in nearby Hampton and Newport News. The calculated population density at 5 miles around the power plant is less than 500 people per square mile. Therefore, if the low population zone boundary facet of the emergency planning zone (EPZ) for an mPower installation can be limited to the site boundary or a small band (5 miles) around the power plant, then this site would warrant further investigation. A hypothetical 40-acre mPower plant placement is represented by the dashed blue box.

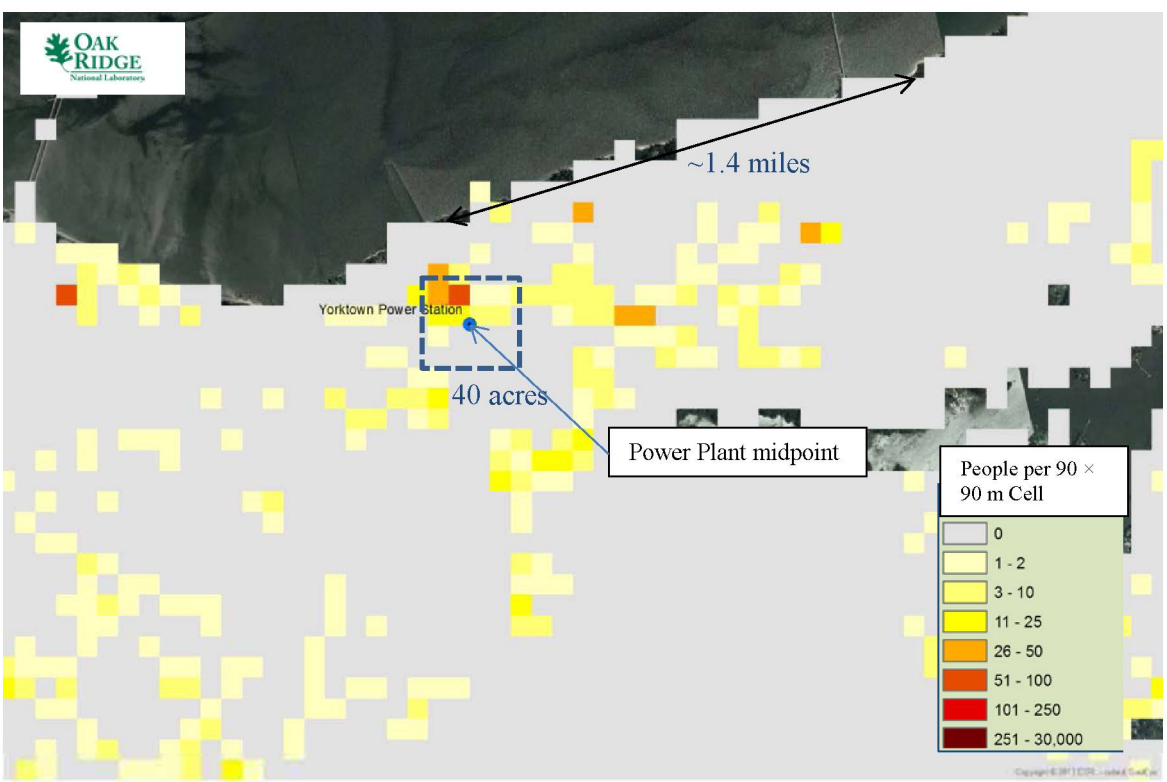

Fig. ES-4. Landscan™ daytime population near the Yorktown Power Station.

As shown in Fig. ES-5, the area in the immediate vicinity of Fort Story is also lightly populated. The fort is lightly inhabited and largely surrounded by parkland and suburban population densities compared with the more urban densities in Norfolk to the south. The calculated population density at 2 miles around the entire fort is less than 500 people per square mile, and for some parts of the fort, the calculated population density at 3, 4, and 5 miles is less than 500 people per square mile. Therefore, if the low population zone boundary facet of the EPZ for an mPower installation can be limited to the site boundary or a small band (2 miles) around the power plant, then this site would warrant further investigation. A hypothetical 40-acre mPower plant placement is again represented by the dashed blue box.

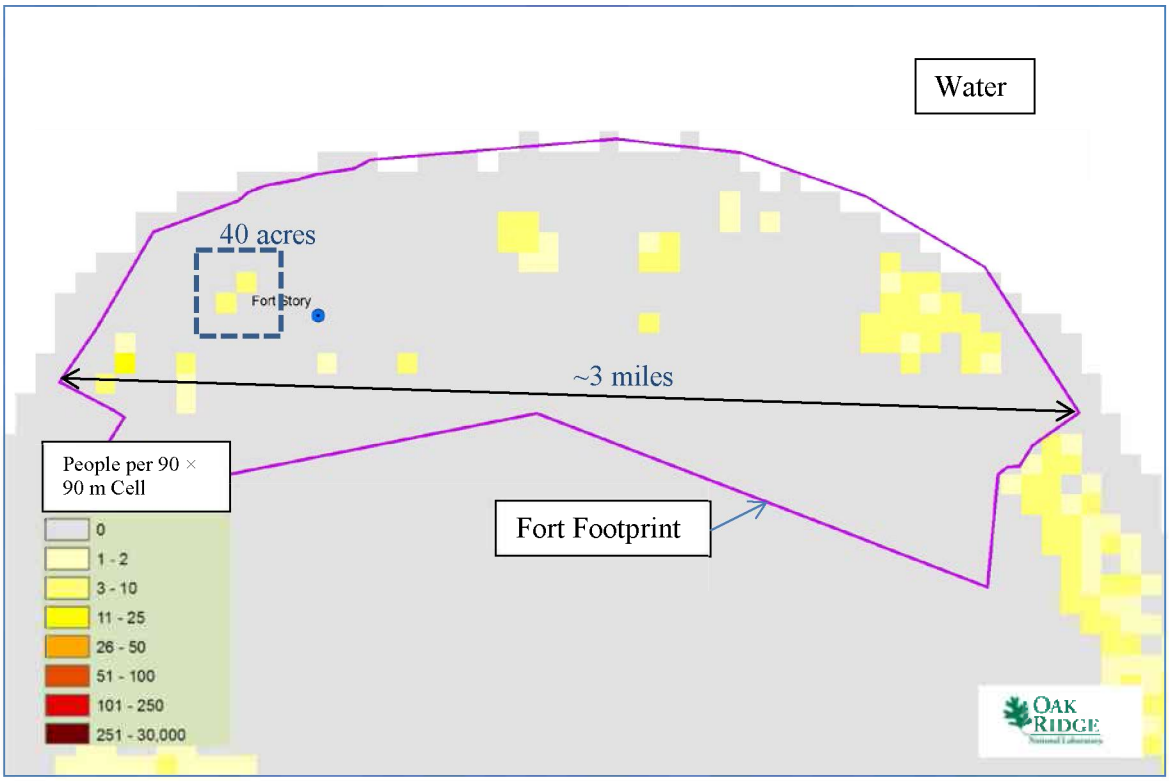

Fig. ES-5. Landscan™ daytime population near Fort Story.

Each of the six sites evaluated in Task 3 has the potential for favorable SMR siting based on initial OR-SAGE review and population density analysis. Therefore, several sites within the Hampton Roads area have potential for favorable deployment of an SMR to provide a means of meeting federal clean energy goals. These sites range in size and proximity to the centroid of the Hampton Roads region. Similar methodology can be applied to other federal energy cluster locations. Based solely on the population density review where the existing population density is less than 500 people per square mile, an EPZ summary (or the low population zone boundary) of the two evaluated sites is shown in Table 1.

Table 1. Summary of two evaluated sites in Task 3

Proposed site	Recommended EPZ based on current population density
Fort Story	2-5 miles
Yorktown Power Station	5 miles

Based on guidance provided by Regulatory Guide 4.7 on siting, all six of the sites considered in Task 3 would be eliminated from consideration based on population density out to 20 miles. Furthermore, all six sites would be eliminated using a more favorable population density calculation at 10 miles, which correlates to the plume exposure pathway EPZ. However, by conducting the initial screen without considering population density (Task 2) and then applying more sophisticated population tools for analysis of select candidate sites, additional options for siting SMRs closer to population centers is feasible. This is dependent on SMR vendors demonstrating that the plume exposure pathway EPZ can be established at a distance less than the standard 10 miles.

Opportunities for siting an SMR inside the standard 10 mile plume exposure pathway EPZ will exist nationwide at older coal plants slated for retirement in urban industrialized areas. Sophisticated population tools can be used to help identify candidate sites that support grid stability and provide clean base load energy. Similar analyses can be performed on other facilities, such as federal facilities, to identify opportunities to meet federal clean energy goals.

ABSTRACT

Geographic information systems technology was applied to analyze federal energy demand across the contiguous US. The Hampton Roads, Virginia, area was identified, along with several other areas, as a significant federal energy cluster. Several Hampton Roads area facilities were previously evaluated for potential to host a small modular reactor (SMR). This study evaluates two of those individual sites for sensitivity to population density. Sensitivity to population density is a significant factor when determining the potential for siting new SMRs and possibly repowering older coal plant sites with SMRs.

1. BACKGROUND, INTRODUCTION, AND METHODOLOGY

1.1 BACKGROUND

The Department of Energy (DOE) Office of Nuclear Energy (NE) has previously tasked the Oak Ridge National Laboratory (ORNL) to support identification of candidate sites for new small modular reactor (SMR) power plants using an ORNL geographic information system (GIS)-based tool.[1,2] Oak Ridge Siting Analysis for power Generation Expansion (OR-SAGE) is a flexible tool being used to evaluate power plant siting options and considerations for a variety of power sources. The objective in developing OR-SAGE was to merge industry-accepted approaches for screening sites with the array of GIS data sources at ORNL to identify candidate areas for a particular application.

Previously, DOE-NE staff members met with members of Virginia-Hampton Roads Small modular reactor Energy Development Council (VSEC) to understand how nuclear energy, particularly SMRs, fit into future plans for secure and reliable energy for the Hampton Roads, Virginia, metro area. This partnership has been promoting the use of SMRs as a means of meeting federal clean energy goals.

The constituents of VSEC are the Jefferson National Laboratory, Huntington-Ingalls Newport News Shipyard, Virginia Electric and Power Company (Dominion), Babcock and Wilcox (B&W) Generation mPower, and an economic development group called the Hampton Roads Military and Federal Facilities Alliance. VSEC has identified a number of potential locations for siting SMRs on or near federal government property. Dominion Energy has performed an initial but limited desktop siting review. The current federal electricity use in this area is estimated by Dominion Energy at over 500 MW with the potential for significant growth based on expansion of the Jefferson Laboratory National Accelerator Facility and other economic growth in the area.

ORNL staff members previously evaluated screening criteria for large and small nuclear power plants, advanced coal plants with carbon sequestration, wet and dry solar power technologies (excluding photovoltaic cells), and compressed air energy storage for the Electric Power Research Institute (EPRI).[3] ORNL staff members also evaluated repowering select coal plants with an SMR[4] and powering select military and DOE facilities with a dedicated SMR.[5]

1.2 INTRODUCTION

The overall objective of this research project is to support DOE-NE in evaluating future electrical generation deployment options for SMRs in areas with significant energy demand from the federal sector. Deployment of SMRs in zones with high federal energy use can provide a means of meeting federal clean energy goals. A report documenting the initial evaluation of energy demand in the federal sector (Task 1 of this project) has been submitted to DOE-NE.[6] The Task 1 report documents additional federal agency energy clusters that may subsequently warrant additional analysis in support of meeting federal clean

energy goals. These federal power clusters were identified based upon power usage data, geographical concentration (collocation) of federal agencies, or operation of large federal data centers. The Hampton Roads, Virginia, area was verified as a potential federal energy cluster by the Task 1 study.

Eleven potential sites in the Hampton Roads, Virginia, area were identified for evaluation by VSEC (Task 2 of this project) as shown in Fig. 1 below and listed in Table 2. The proposed sites are represented as blue dots and labeled on the regional map below (Fig. 1). The site evaluations were based on previously developed screening criteria and the application of spatial modeling and GIS. For reference purposes, a generalized SMR plant parameter envelope for the B&W Generation mPower integral technology is used for all site evaluations. The B&W technology is based on existing pressurized-water reactor (PWR) technology. The mPower design is characterized as an "integral" PWR (iPWR) since these plants will have major equipment such as pumps, steam generators, and pressurizers all located within the pressure vessel in an integrated, compact design. Task 3 will include focused population density studies on two of these sites.

Fig. 1. Regional view of evaluated Hampton Roads sites.

A summary of the site selection and evaluation criteria (SSEC) chosen for the Hampton Roads site evaluations is provided below.

- Wetlands and open water are excluded.
- Protected lands (e.g., national parks, historic areas, wildlife refuges) are excluded.
- Land with moderate or high landslide hazard susceptibility is avoided.
- Land that lies within a 100 year floodplain is excluded.
- Land with a slope of greater than 18% (~10°) is avoided.

- Land areas that are more than 20 miles from sufficient cooling water makeup sources (at least 30,000 gpm), based on a 360 MW(e) modular iPWR installation, are excluded for mPower iPWR plant applications.
- Land too close to identified fault lines is avoided. (The length of the fault line determines the standoff distance.)
- Land located in proximity to hazardous facilities (airports and oil refineries) is avoided.
- Land with safe-shutdown earthquake peak ground acceleration (2% chance in a 50 year return period) greater than 0.5 g is excluded.

These parameters are tracked on a cell-by-cell basis for the entire contiguous US. A more detailed discussion of each criterion is available in the general SMR siting report[2] provided to DOE-NE in September 2012. The OR-SAGE tool tracks the SSEC parameters for each 100 × 100 m cell. The cells are color coded to clearly illustrate multiple unmet SMR siting criteria. A green square has no siting issues relative to the selected SMR SSEC values; a yellow square has a single siting issue; an orange square has two siting issues; and a blue square has three or more siting issues. Cells that are clear of all the SSEC layer exclusions can be displayed, and cells tripped by one, two, or three or more exclusions can be tracked and displayed. This composite map (Fig. 2) is a powerful feature of the OR-SAGE tool because it allows areas with a limited number of siting challenges to be identified. Engineering solutions may be available for areas with just one or two siting challenges.

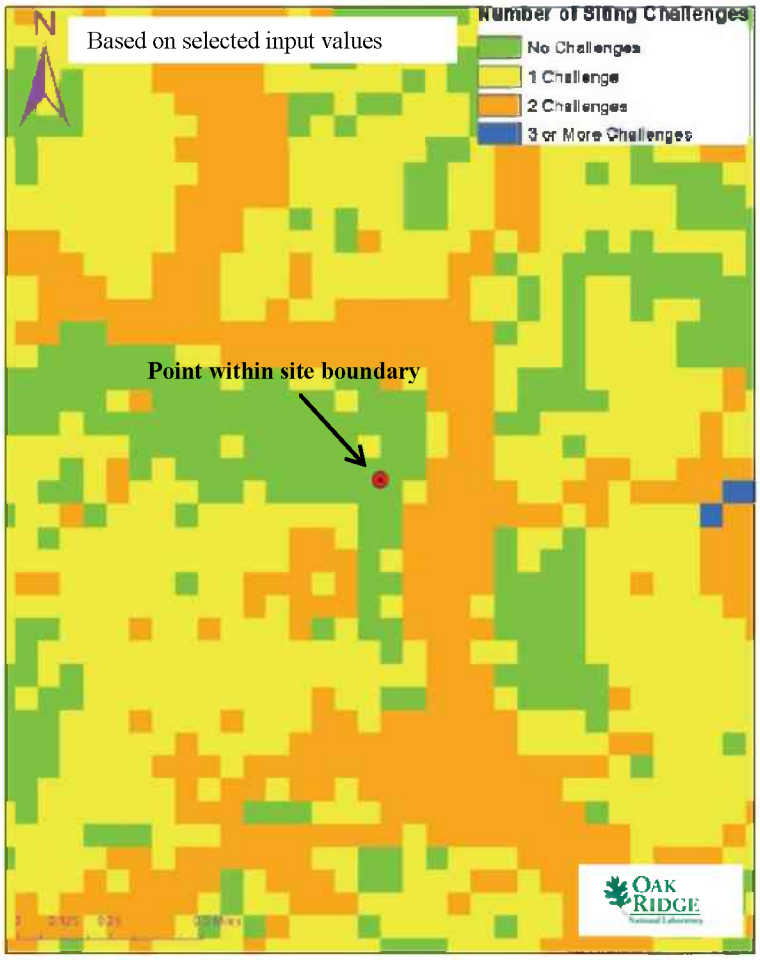

Fig. 2. Nominal, bounding SMR small-scale composite map (Chesapeake Power Station).

Based on preliminary design information and expert judgment, it is assumed that most SMR base design packages can be accommodated on a 50 acre footprint. In general, more than 50 acres are available at each of the eleven evaluated sites. The mPower iPWR footprint is advertised at 40 acres.

A data package and analysis for each site in the sample set was prepared in Task 2, and the results were reported to DOE-NE by letter report[7]. A brief summary of these evaluations is available in Appendix A of this report. The complete set of evaluations is available in the Task 2 letter report.

A satellite aerial view of each facility location is also available in the Task 2 letter report. This provides a convenient look at the area topography, including nearby major roads, rivers, and population activity such as towns and subdivisions. Satellite aerial views of the sites of interest are an essential part of the analysis.

Table 2. List of eleven evaluated sites in the Hampton Roads area

Proposed site	Owner	Task 2 GIS evaluation
Camp Peary	US Department of Defense	2 partial siting issues
Chesapeake Power Station	Dominion Resources	2 partial siting issues
Craney Island	US Department of Defense	3 partial siting issues
Fort Eustis	US Army	3 partial siting issues
Fort Story	US Army	2 partial siting issues[a]
Langley Air Force Base	US Air Force	1 full, 2 partial siting issues[a]
Little Creek Amphibious Base	US Navy	1 full, 4 partial siting issues
Norfolk Naval Base	US Navy	2 partial siting issues[a]
Surry Nuclear Power Station	Dominion Resources	1 full, 4 partial siting issue[a]
Yorktown Naval Weapons Station	US Navy	3 partial siting issues
Yorktown Power Station	Dominion Resources	1 full, 2 partial siting issues

[a]Erroneous hazards siting issue shown based on map edge effects

Based on the analyses of Task 2[7], each of the eleven individual sites was binned into one of three categories:

1. Exclusive of population, the site meets multiple conventional standards for consideration of siting an SMR at the proposed location. There are no current or near-term foreseeable SMR SSEC siting issues that should preclude this site from further SMR siting consideration.
2. Exclusive of population, the site meets multiple conventional standards in the near term for consideration of siting an SMR at the proposed location, but there may be longer term issues that could preclude this site from further SMR siting consideration. For example, the site may be heavily developed with little room for expansion necessary to site an iPWR.
3. The site is not a likely candidate for consideration of siting an SMR. Numerous SSEC are not met or other parameters exist that could make it difficult to site an iPWR.

1.2.1 First Group of Site Evaluations

Five of the eleven sites were rated as the most favorable for siting an iPWR. These sites have significant space that meets all screening criteria, or the issues are well understood and are judged not to impact iPWR siting at that location. These sites are (listed in alphabetical order):

- Camp Peary,
- Chesapeake Power Station,
- Surry Nuclear Power Station,
- Yorktown Naval Weapons Station (Naval Weapons Annex), and
- Yorktown Power Station.

1.2.2 Second Group of Site Evaluations

Four of the remaining sites are rated in the second category for siting an iPWR. These sites are generally favorable for siting an iPWR but are identified as having at least one significant issue to overcome (identified in parentheses below). These sites are (listed in alphabetical order):

- Craney Island (wetlands and protected lands),
- Fort Story (wetlands),
- Langley Air Force Base (wetlands and protected lands), and
- Norfolk Naval Base (protected lands).

1.2.3 Third Group of Site Evaluations

The final two sites are rated as not likely candidates for siting an iPWR. These sites have identified hazards that will be difficult to overcome (identified in parentheses below). These sites are (listed in alphabetical order):

- Fort Eustis (airport proximity, wetlands, protected lands, site infrastructure) and
- Little Creek Amphibious Base (airport proximity, wetlands, floodplain, protected lands, site infrastructure).

1.3 APPROACH AND METHODOLOGY

The focus of this report (Task 3) is to analyze two of the evaluated sites from Task 2 for sensitivity to population density. Sensitivity to population density is a significant factor of interest in the potential for siting new SMRs and possibly backfitting SMRs into older coal plant facilities or other facilities near population centers (source of load demand). Based on the Task 2 analyses and an initial evaluation of population density averaged over a radial distance out to 10 miles[†], the Surry Power Station, Camp Peary, and the Yorktown Weapons Station (Naval Weapons Annex) would clearly be top potential candidates for hosting an iPWR to support federal power needs. All of these sites have significant space. Furthermore, none of these sites have significant population issues evaluated out to a distance of 10 miles. Therefore, while these are excellent candidate sites, a population density sensitivity analysis of these three locations

[†]Note that 10 miles is half the distance of 20 miles recommended in Nuclear Regulatory Commission (NRC) Regulatory Guide 4.7[8] for evaluating population density. The 10 mile area was used due to the potential for SMRs to have a smaller source term compared to current light-water reactors and correlates to the plume exposure pathway EPZ. The NRC has not provided siting guidance tailored specifically for SMRs. No actual mPower source term analysis has been completed.

would not be especially informative for the purposes of this study. A summary of the Task 2 analyses for these three sites is available in Appendix A of this document. Complete analyses results for all 11 sites are available in the Task 2 letter report[7].

Likewise, Fort Eustis and the Little Creek Amphibious Base were previously evaluated as unlikely candidates for siting an iPWR based on siting factors unrelated to population density. Therefore, these two facilities were not considered for additional population density sensitivity analysis.

This left six candidate sites from the Task 2 analyses from which to select two sites for further in-depth sensitivity analysis of population density as proposed by the Task 3 description. A summary of the Task 2 analyses for these six sites is available in Appendix B of this document. Task 3 calls for the performance of population density sensitivity studies at 0.5 miles, 1 mile, 2 miles, 5 miles, and 10 miles from a proposed site centroid. However, a radius of 0.5 miles is less than the population database resolution used in the OR-SAGE tool and cannot be analyzed. Therefore, regional population density analyses based on the Nuclear Regulatory Commission (NRC) Regulatory Guide 4.7[8] approach was revised and conducted at distances of 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, and 10 miles. These plots are shown in Sect. 2.1. In addition, localized LandScan™ plots of each of the six facilities were evaluated. The ORNL LandScan™ database is a highly sophisticated population database that provides high-resolution global population distribution data representing day, night, or ambient population (averaged to account for seasonal and daily variations). Based on this initial screen and the Task 2 results, the Yorktown Power Station and Fort Story were selected for further detailed population density evaluation.

Based on guidance provided by Regulatory Guide 4.7 on siting, locations exceeding 500 people per square mile would be eliminated from consideration based on population density calculations out to 20 miles. This would include most of the sites from the Task 2 analysis. Furthermore, most of the Task 2 sites would also be eliminated using a more favorable population density calculation at 10 miles, which correlates to the plume exposure pathway EPZ. However, the goal of the Task 3 analysis is to show that by conducting the initial screen without considering population density (Task 2) and then applying more sophisticated population tools for analysis of select candidate sites, additional options for siting iPWRs closer to population centers is feasible. This is dependent on iPWR vendors demonstrating that the plume exposure pathway EPZ can be established at a distance less than the standard 10 miles.

2. EVALUATION OF TWO HAMPTON ROADS AREA SITES

The initial phase of this project characterized all land in the contiguous US to possibly site new SMR nuclear power plants in areas where the concentration and electricity use by federal government agencies is high and forecasted to grow in the next 10 years. "Federal agencies" include military and other agencies (e.g., Homeland Security, DOE, Federal Bureau of Investigation, and Social Security Administration) that have missions of national critical importance.

Among regions providing favorable opportunities for siting an mPower plant (an iPWR), the Hampton Roads area was identified as the region with the highest clustered federal energy demand. According to informal Dominion Resources records, the power demand for federal facilities in the area is more than 500 MW(e). Therefore, this area is highly suitable for investigating use of an iPWR to help meet federal clean energy goals.

2.1 POPULATION ANALYSIS

NRC siting guidance[8] recommends calculating the population density within 20 miles of the site and avoiding population densities of greater than 500 people per square mile. Current iPWR vendors identify the ability to replace smaller, aging coal plants with iPWRs having a similar capacity and footprint as an advantage of the various iPWR designs. In order to realize this advantage, iPWRs will need to be located closer to population centers where many of these coal plants already exist. Due to their smaller capacity, iPWRs will have smaller source terms than larger reactors, and the appropriate evacuation zone is an issue still under discussion with the NRC staff. For the purposes of previous SMR studies, a 10 mile buffer was deemed appropriate for initial SMR siting evaluations, which correlates to the plume exposure pathway EPZ. This value is variable within the database and is evaluated further for selected sites in Task 3 of the project and documented in this report.

To meet the guidance, each cell in the database is queried for ambient population, which considers the weighted transient population (essentially an average of the daytime and nighttime populations). If a cell population is greater than 500 people per square mile, it is immediately excluded. If a cell population is less than 500 people per square mile, the surrounding area is evaluated by calculating the population density in an expanding set of rings out to a maximum of 10 miles (in simple terms, a buffer zone). If any ring is calculated to have a population density above 500 people per square mile, then the center cell is excluded. If no ring around the central cell exceeds a population density of 500 people per square mile, then the cell remains viable with regard to population. From the Task 2 analysis, Fig. 3 shows the regional result of a population dataset query with a 10 mile buffer distance considered. Green and brown area indicates land mass and blue area indicates water bodies. The red areas represent land mass that exceeds a population density of 500 people per square mile evaluated out to 10 miles from each 100 × 100 m cell. This is the approach taken to construct the population density layer for the OR-SAGE SMR analysis. It can be seen from Fig. 3 that Camp Peary, the Surry Nuclear Power Station, and the Yorktown Naval Weapons Station (Naval Weapons Annex) are at the edge of this analysis area or completely clear of population density effects at 10 miles. The site boundaries of these three facilities contain substantial space outside the evaluated 10 mile population density zone.

Camp Peary, the Surry Nuclear Power Station, and the Yorktown Naval Weapons Station (Naval Weapons Annex) were previously evaluated as favorable for iPWR siting in the Task 2 analysis. These sites would be very favorable for further study for actually siting an iPWR to meet federal clean energy goals for the Hampton Roads area. However, for the purposes of a population density sensitivity evaluation, these sites are less interesting than other sites in the area, because these sites currently do not have a population density issue. Therefore, it is desirable to select sites closer to the center of all the federal facilities in the area to examine population densities in more detail.

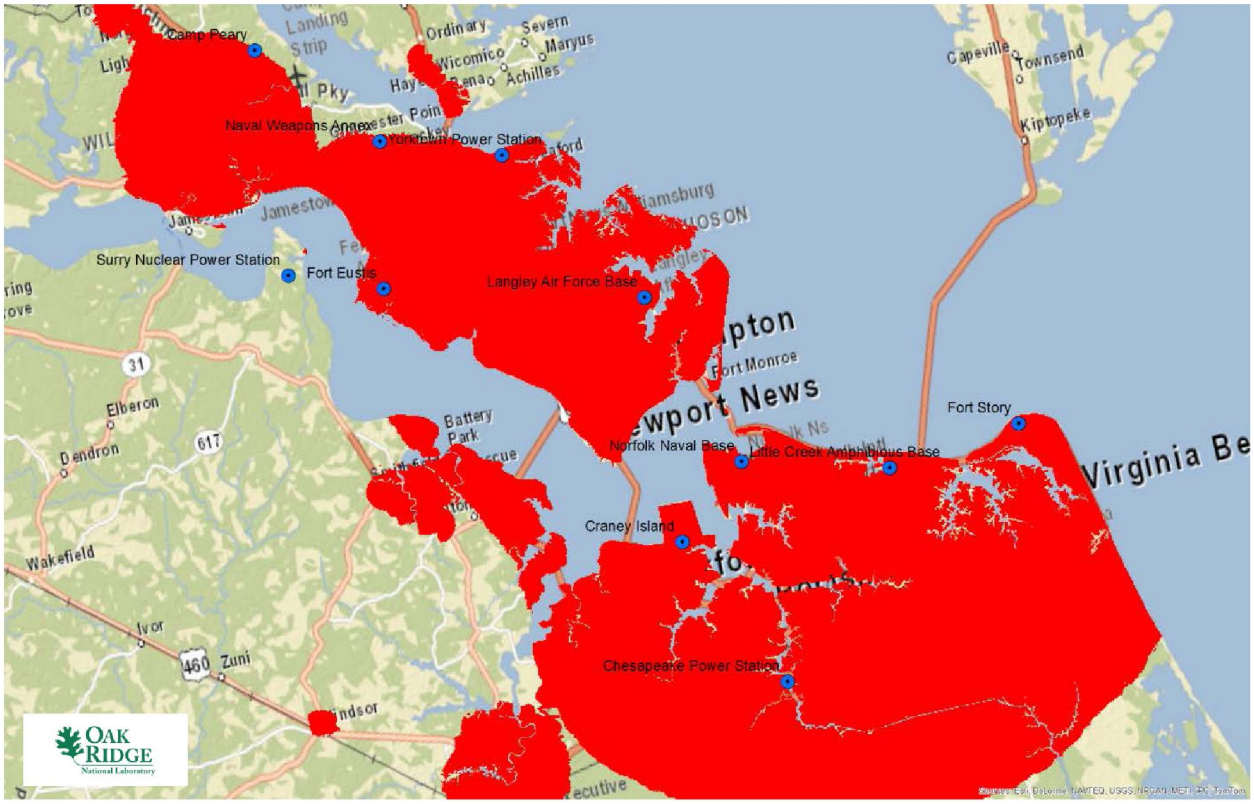

Fig. 3. Regional population density GIS layer (500 people per square mile within 10 miles)

An alternative to the calculational approach to population density used by the OR-SAGE tool is to directly apply the ORNL LandScan™ database. The ORNL LandScan™ database is a highly sophisticated population database that provides high-resolution global population distribution data representing an ambient population (averaged to account for seasonal and daily variations). The LandScan™ algorithm uses spatial data and imagery analysis technologies and a multi-variable dasymetric modeling approach to disaggregate census counts within an administrative boundary. LandScan™ is readily adaptable to various socio-environmental studies, including exposure/heath risk assessment, urban sprawl estimation, and estimating population at risk from natural and anthropogenic disasters. It uses an innovative approach with GIS and remote sensing technologies with various spatial information sources to reconstruct synthetic population distribution databases. LandScan™ has two databases, the LandScan Global and LandScan USA. The Landscan Global database is used for the OR-SAGE population density calculations and has a spatial resolution of 1 km. The LandScan USA database, used for the comparison figures in this analysis, has a spatial resolution of 3 arc seconds (~90 m) that covers the continental US, Alaska, and Hawaii. Each database has two layers, a nighttime and a daytime population distribution.

A sample output from LandScan Global for the Hampton Roads region is shown in Fig. 4. Areas in orange and dark red in Fig. 4 have higher population density. This figure provides some directionality of the population density relative to the proposed sites, identified as blue dots. This figure also provides some added insight on the viability of the proposed sites. Gray areas in Fig. 4 represent low population zones. The gray areas reinforce the viability of Camp Peary, the Surry Nuclear Power Station, and the Yorktown Naval Weapons Station as potential sites to host an iPWR. Other facilities more completely contained within the OR-SAGE population density calculation at 10 miles depicted in Fig. 3 show greater promise when observed in Fig. 4. Areas of interest can subsequently be evaluated for population density using 90 × 90 m cells from the LandScan USA database.

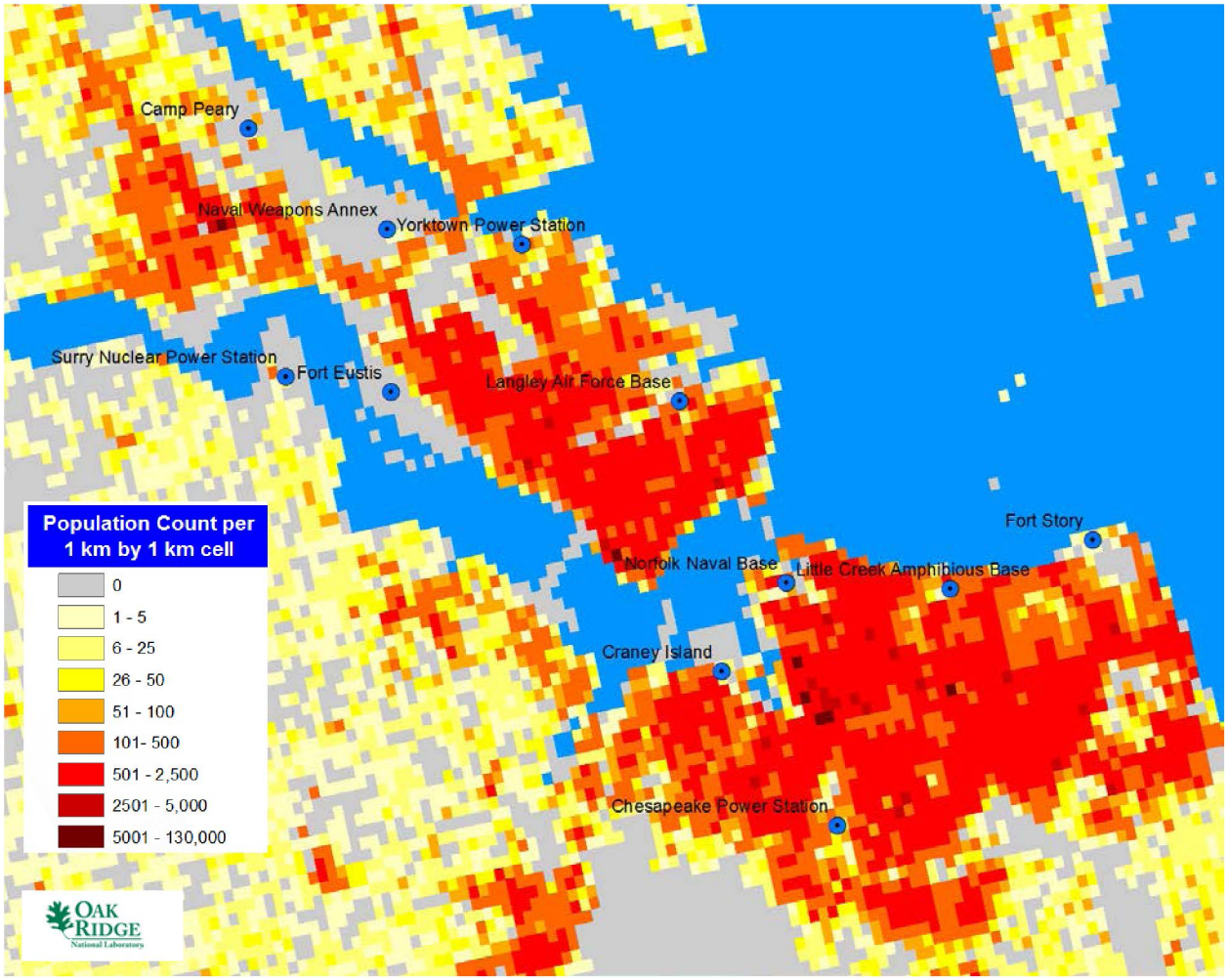

Fig. 4. Regional population density by cell (orange and red indicate higher population density).

Based on this high-level evaluation of population density, the Yorktown Power Station and Fort Story were selected for additional analysis of sites that would have been otherwise excluded based on the standard population guidance of Regulatory Guide 4.7. A quick evaluation of the Chesapeake Power Station is also included based on the interesting seam in population density shown in Fig. 4 above.

2.1.1 Population Density Calculation at Various Distances

The OR-SAGE population density calculation can be performed for each of the more than 700 million cells in the database at any distance of interest. Individual cells that exceed 500 people per square mile at any distance evaluated less than 10 miles will be contained within the 10 mile evaluation shown in Fig. 3. This is true because of the manner in which the calculation is performed, as described previously. The progression of land mass that becomes excluded as the population density calculations are performed at increasing intervals is informative regarding the absolute population density in any given area and whether the population is fairly compact or is sprawled across a wider area. The figures shown in the following progression from Fig. 5 through Fig. 10 demonstrate cumulative population density calculations starting at a 1 mile diameter from an individual cell center and proceeding through 2, 3, 4, 5, and 10 miles.

Note that if a cell is tripped at a smaller diameter, it will also be tripped at all larger diameters. For example, cells that exceed 500 people per square mile at a 1 mile diameter are purple in Fig. 5. Those same cells appear in blue in the 2 mile calculation shown in Fig. 6, along with the new cells that tripped using the 2 mile calculation, and so forth, through Fig. 10.

Cumulative results from Fig. 5 through Fig. 10 are shown in Fig. 11. In Fig. 11, the area where population density exceeds 500 people per square mile at a 1 mile diameter is presented as the base color (purple as in Fig. 5). The differential area that is added by a similar calculation at a 2 mile diameter is shown in blue (the same color used in Fig. 6). In this case, the blue and purple areas combined are equivalent to the area shown entirely in blue in Fig. 6. Likewise, the differential area for the population densities at 3 miles (green), 4 miles (yellow), 5 miles (orange), and 10 miles (red) are displayed in the cumulative plot in Fig. 11. Note that the population density calculation for some towns in the Hampton Roads area do not change much from the initial 1 mile calculation shown in purple. This indicates little population sprawl in the vicinity of these outlying towns. Note also that the population density calculation rings for the larger population centers are interrupted by the water in the area. As the population density is evaluated over a large enough area, some of these population density bands leap across the body of water. This is the case for the red ribbon of land (10 mile population density calculation) southwest of Newport News in Fig. 11. The small town of Smithfield, Virginia, is relatively compact, but it is on the fringe of being cloaked by the Newport News population density evaluated at 10 miles. If the population density calculation were performed at 20 miles per Regulatory Guide 4.7, much of the southern bank of the James River would become excluded at 500 people per square mile.

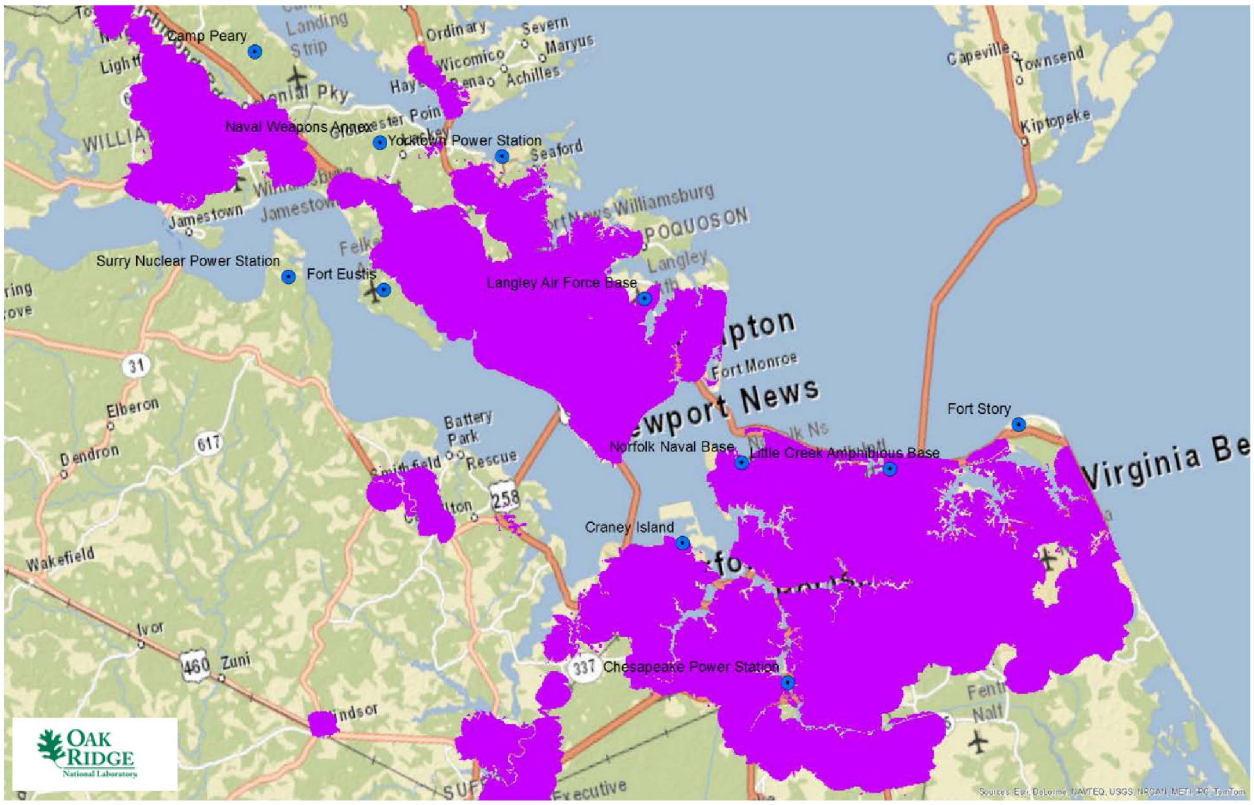

Fig. 5. Population density exceeding 500 people per square mile within 1 mile of a cell center.

Fig. 6. Population density exceeding 500 people per square mile within 2 miles of a cell center.

Fig. 7. Population density exceeding 500 people per square mile within 3 miles of a cell center.

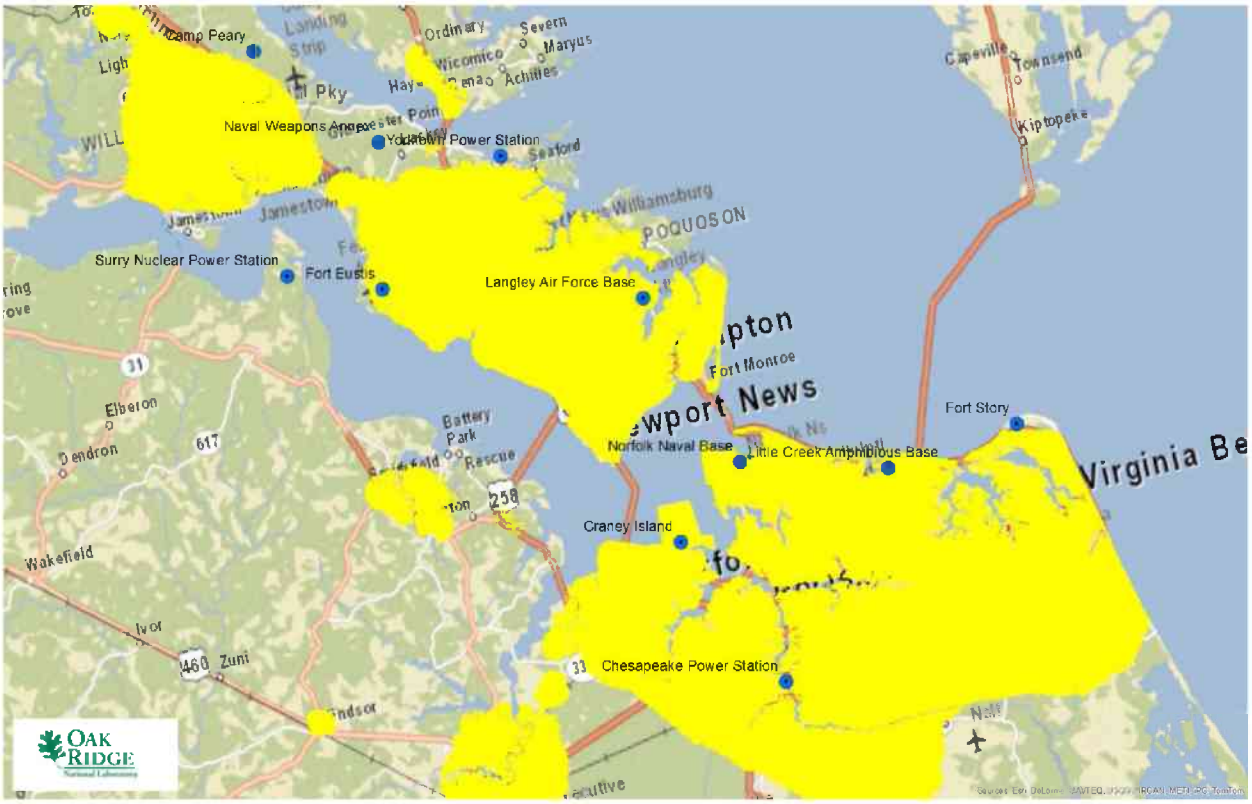

Fig. 8. Population density exceeding 500 people per square mile within 4 miles of a cell center.

Fig. 9. Population density exceeding 500 people per square mile within 5 miles of a cell center.

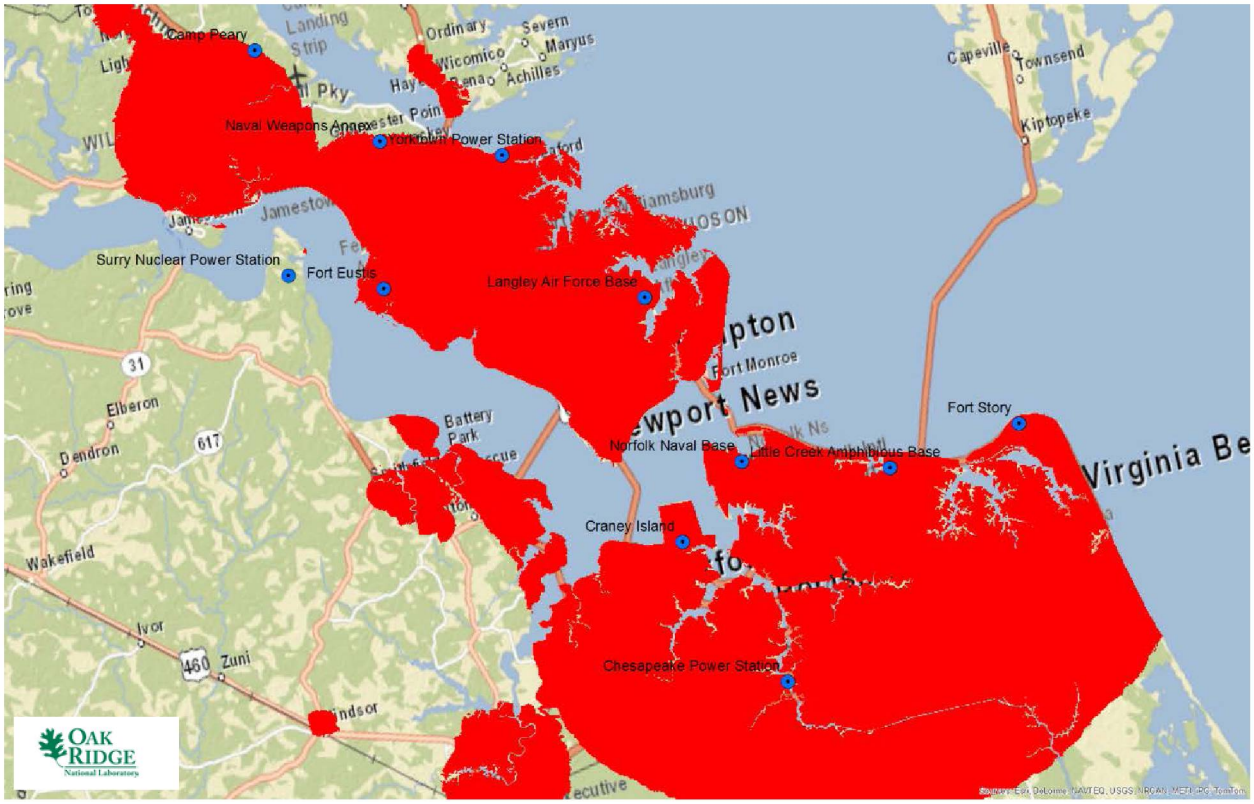

Fig. 10. Population density exceeding 500 people per square mile within 10 miles of a cell center.

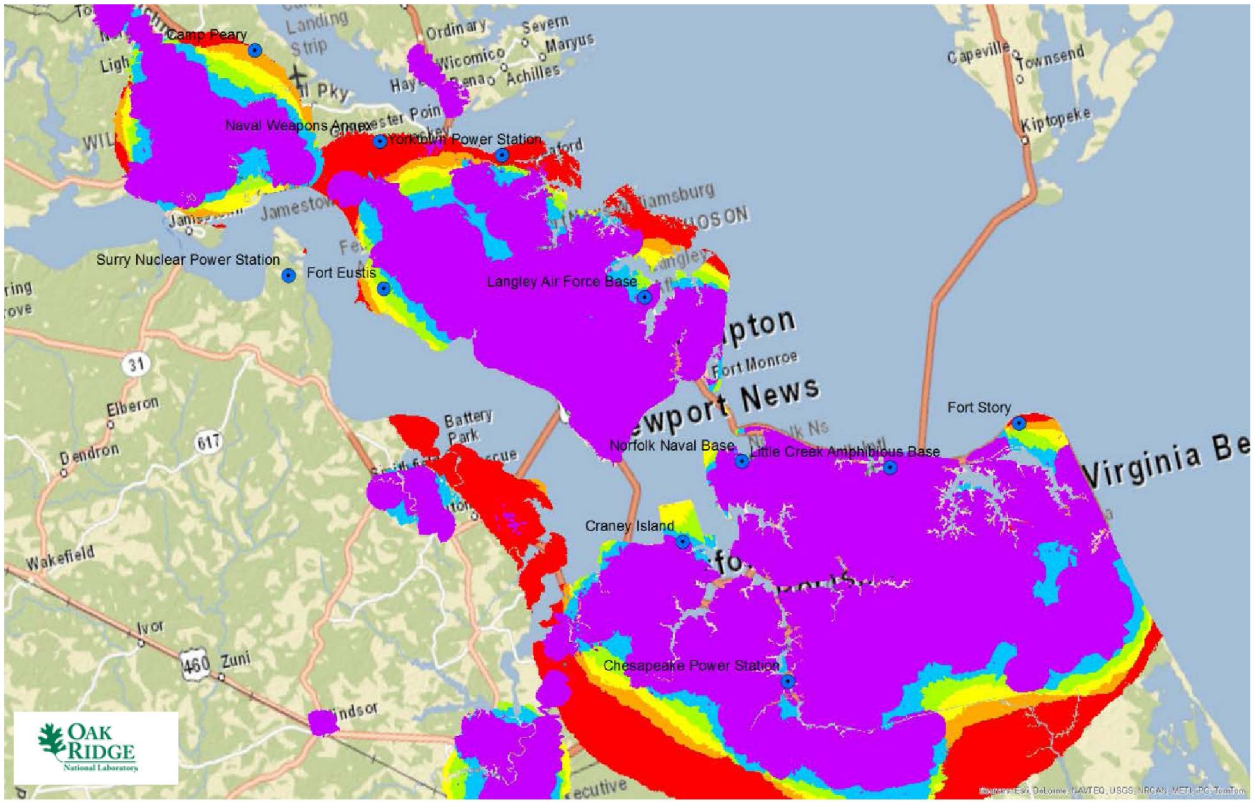

Fig. 11. Cumulative population density calculations within 1, 2, 3, 4, 5, and 10 miles of a cell center.

The plot in Fig. 11 is useful in many ways. It is possible to observe where the densest population occurs within a populated region (ostensibly within the purple mass). This information can aid in optimizing the placement of new power generation sources, new substations, transmission lines, etc.

In this case, Fig. 11 shows the eleven facilities of interest from Task 2 and their relationships to areas of differing population density calculations. If a micro-grid supporting all the federal facilities in the area is desirable, then selecting a facility toward the centroid of the region may be the most desirable choice. If simply adding sufficient green energy to account for federal facility energy use to the general grid is the goal, then one of the more outlying sites with less population impacts may be the better choice.

2.1.2 Review of Site Sample Set for Task 3

Section 1.3 describes the process of identifying the six sites that might be the most worthwhile to subject to further population density sensitivity analysis. The Yorktown Power Station (Appendix B.6) to the north is only impacted by the 10 mile population density calculation, making the site a good candidate overall. Langley Air Force Base (Appendix B.4) has area north of the runway onsite that is less densely populated. There is potential for more detailed population density analysis at the site. The Norfolk Naval Base (Appendix B.5) has area toward the piers that is less densely populated. In addition, nuclear powered ships routinely dock at the piers. Heavy infrastructure on the site could make it difficult to find 40 acres to site an mPower iPWR, but there is opportunity for more detailed population density analysis at the site. Craney Island (Appendix B.2) includes area in the peninsula (dredged material) into the James River that is less densely populated. Navy fueling operations may preclude further siting considerations, but there is opportunity for more detailed population density analysis at the site. Fort Story (Appendix B.3) is located on Cape Henry, a lower population density point at the mouth of the Chesapeake Bay, making the site a good candidate overall. Finally, the Chesapeake Energy Center (Appendix B.1) along the Elizabeth River lies on a low population density seam in an otherwise dense population zone. There may be siting potential to use the existing electrical infrastructure at this site. The information presented in Fig. 11 reinforces the decision to further analyze the Yorktown Power Station and Fort Story regarding population density effects.

2.2 ANALYSIS OF THE YORKTOWN POWER STATION

The Yorktown Power Station sits at the mouth to the York River near the historic Yorktown battlefields. The Yorktown Power Station is a three unit plant; two units burn coal, and the third unit burns oil. The total site capacity is 1141 MW(e). The coal units are designated as Unit 1 and Unit 2 and are slated to be shut down in 2015. Unit 1, commissioned in 1957, is rated at 159 MW(e), and Unit 2, commissioned in 1958, is rated at 164 MW(e). Unit 3, commissioned in 1974, is rated at 818 MW(e). The units are cooled by once-through cooling from the adjacent York River. In terms of cooling water required, site infrastructure, and electrical output to the grid, a dual unit mPower would be a reasonable substitution for the existing coal-fired Units 1 and 2. A dual unit mPower plant would provide 360 MW(e), replacing the combined 323 MW(e) of coal-fired Units 1 and 2

A satellite view of the Yorktown Power Station vicinity is provided in the Google Earth snapshot in Fig. 12. The power plant is estimated to sit on 250 acres to the left in Fig. 12. Two large oil tanks associated with the power plant are out of view to the south. There is an adjacent oil refinery that is no longer in use. This could provide approximately 400 additional acres of land for siting an mPower iPWR, which requires approximately 40 acres of land.

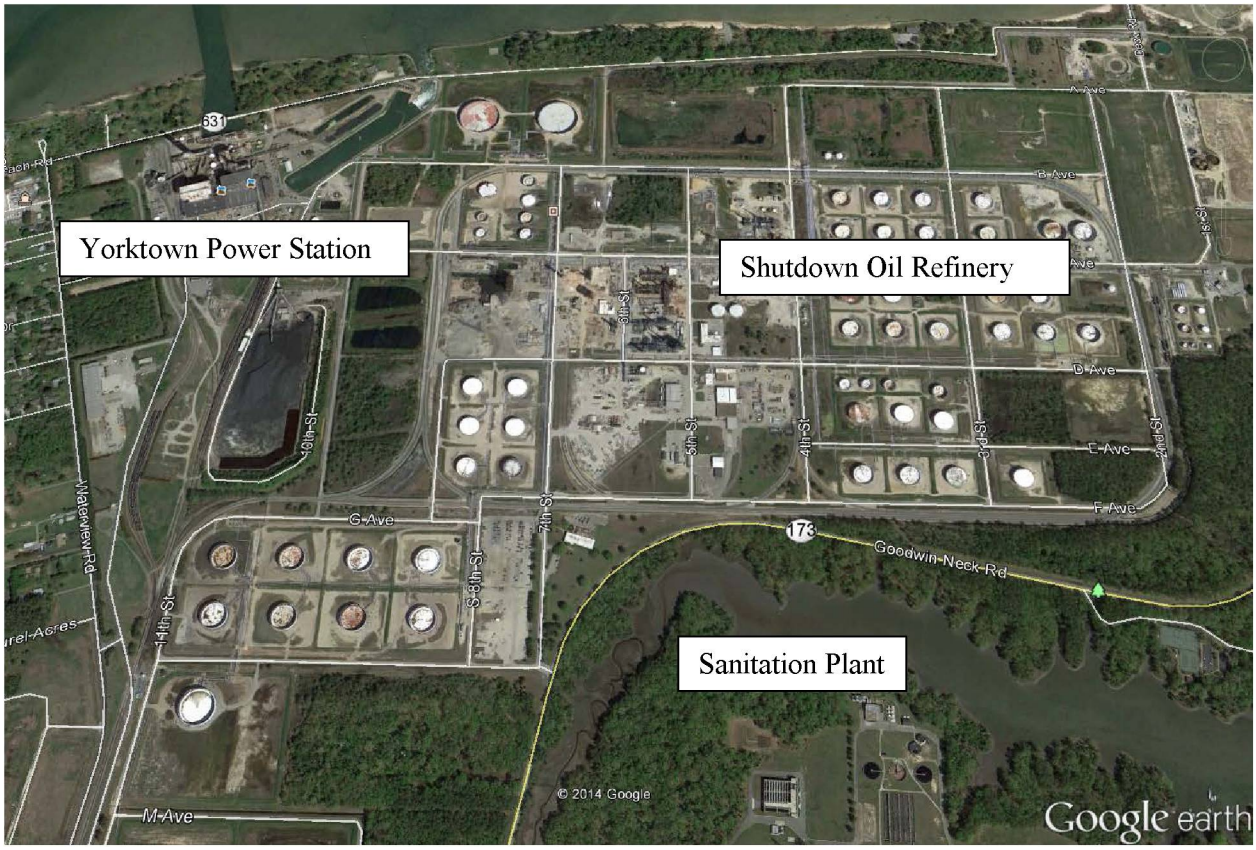

Fig. 12. Yorktown Power Station (Google Earth).

The analysis from Task 2 identified two siting issues: inadequate freshwater stream flow within 20 miles to provide required cooling water makeup, and proximity to hazards. Areas excluded by these analyses are identified in magenta in Fig. 13. While the area has inadequate freshwater stream flow overall to support closed-cycle cooling water makeup needs, available once-through cooling water should be adequate and comparable to the demand of the current coal plants slated for closure. The once-through cooling infrastructure is in place. The identified hazards include the oil refinery which is no longer in operation, and the Newport News/Williamsburg International Airport. The airport is actually not a factor as shown by the arc in the lower portion of the hazards figure, well clear of the power plant. Therefore, there is no actual hazards issue at the site (red dot in Fig. 13).

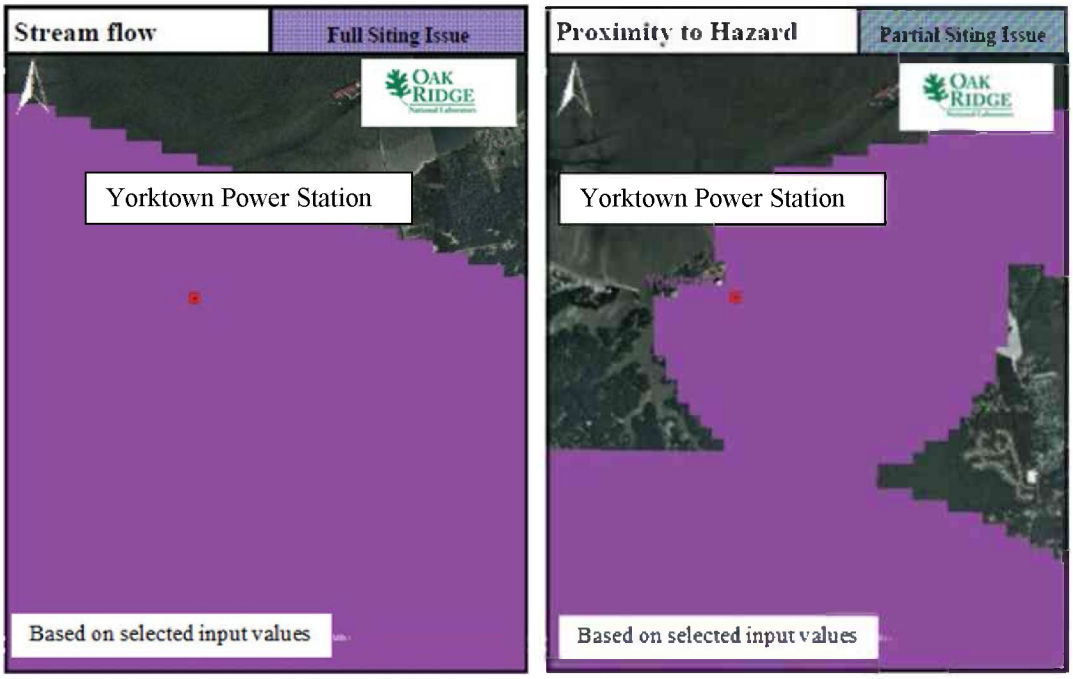

Fig. 13. OR-SAGE siting issues for the Yorktown Power Station.

Population density data from the LandScan USA database for the Yorktown Power Station is shown in Fig. 14 (daytime) and Fig. 15 (nighttime). Each square cell in the LandScan USA display is 90 × 90 m, which is slightly smaller than the standard OR-SAGE 100 × 100 m cell[‡]. Cell color indicates the actual population count (bin) for that square (2 acres). The blue dot in each figure represents the location of the power plant turbine building. The daytime population density in Fig. 14 indicates the daytime workforce at the power station, the shutdown oil refinery, and the sanitation plant, all in the center of Fig. 14. Note the contrast with the nighttime population density in Fig. 15, which is largely gray (zero density) in the center of the map. The blue dashed-line square in Fig. 14 and Fig. 15 is a representative 40 acre plot that could accommodate an mPower iPWR. The hypothetical 40 acre plot is intended to provide a size reference relative to the industrial area and the surrounding daytime and nighttime population density. The blue dashed-line square is not intended to project the actual or recommended placement of an mPower iPWR power plant.

The power plant and the shutdown oil refinery span across approximately 1.4 miles of waterfront on the York River as shown in Fig. 14. This would provide ample opportunity for siting an iPWR at this location.

[‡]OR-SAGE bases the calculated population on the Landscan Global database, which provides an ambient population count (a weighted average of the daytime and nighttime populations). The Landscan Global data has a spatial resolution of 1 km.

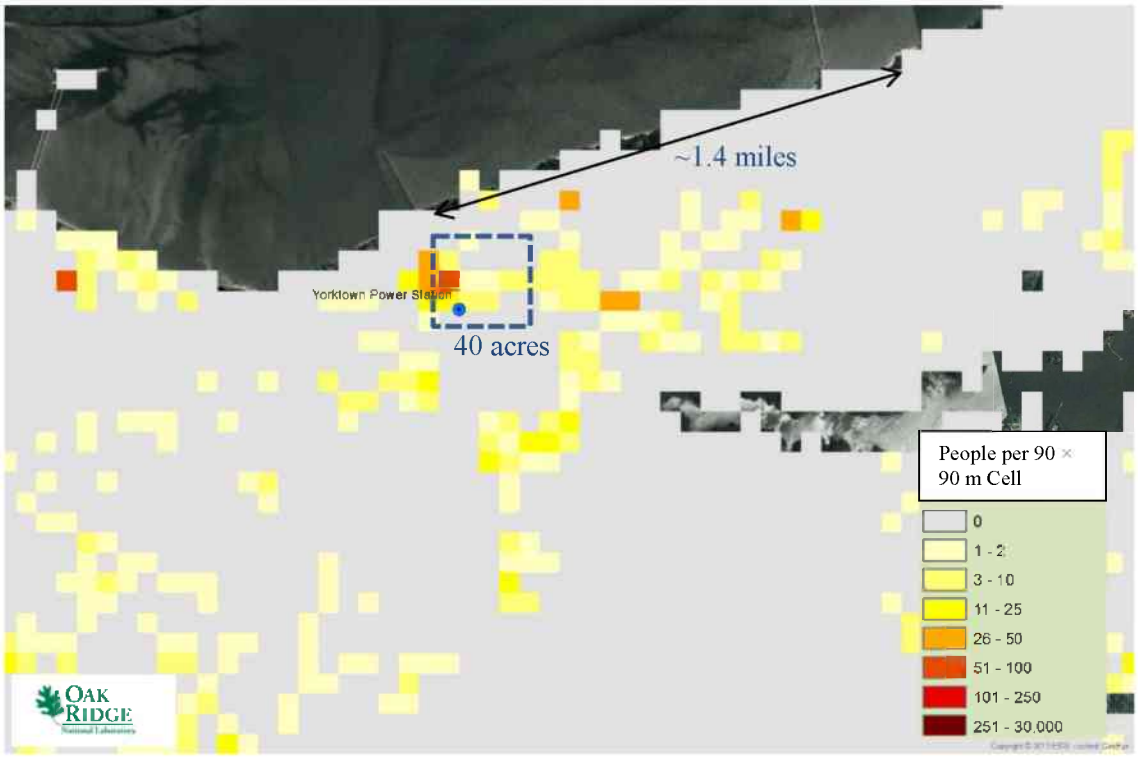

Fig. 14. Landscan™ daytime population near the Yorktown Power Station.

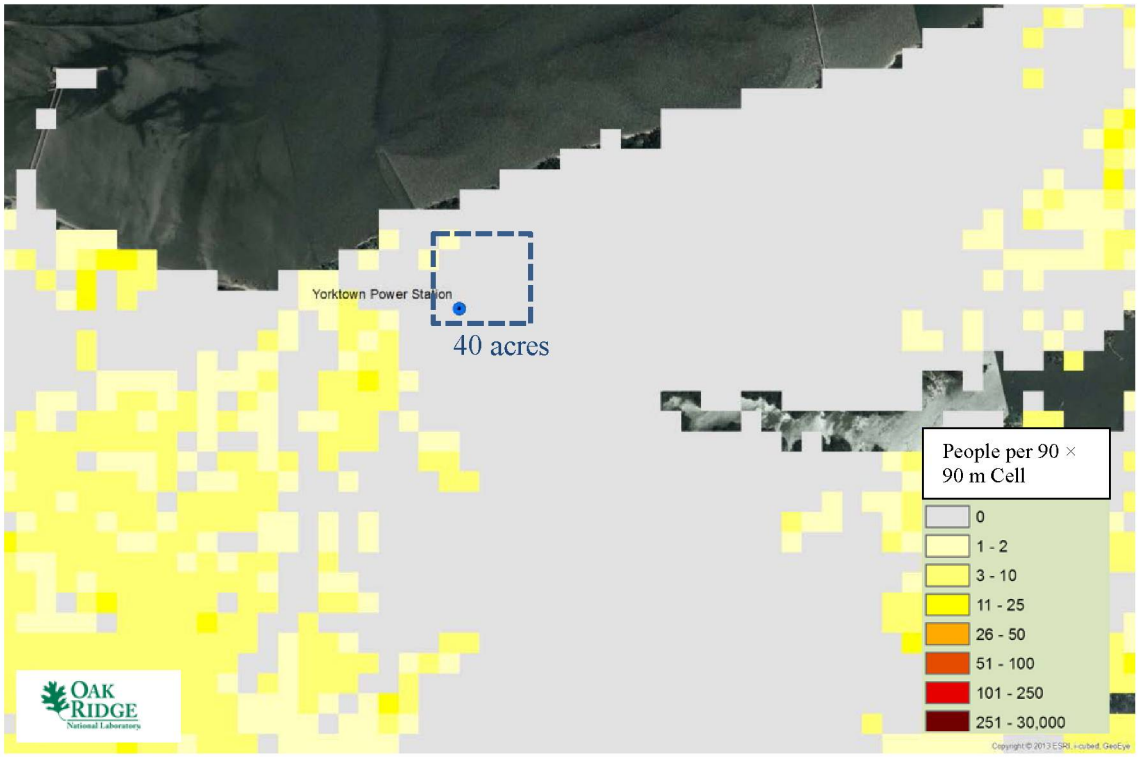

Fig. 15. Landscan™ nighttime population near the Yorktown Power Station.

A cumulative OR-SAGE calculated population density plot around the Yorktown Power Plant is shown in Fig. 16. (See the discussion regarding the development of the cumulative population density figure in Sect. 2.1.1.) The detail in Fig. 16 is a magnification of the area around the Yorktown Power Plant from Fig. 11. The individual cells of land in the OR-SAGE database start to become visible in this figure. The detail of Fig. 16 shows that the Yorktown Power Station is only impacted at a calculated population density of 10 miles. Looking at this from the opposite perspective (or the plant perspective), the calculated population density at 5 miles (next lower calculation ring in Fig. 16) around the power plant is less than 500 people per square mile. This can easily be confirmed visually by Fig. 9. This can be calculated more precisely by continuing the calculation radii in 1 mile increments from 5 miles out to 10 miles and observing exactly where the plant was included in a cumulative population density plot similar to that in Fig. 16. Using the current ambient population calculation, a utility would likely need to evaluate an emergency planning zone (EPZ) at five miles or less for this location. Expected future population growth would also need to be evaluated.

The plots in Fig. 14 and Fig. 15 confirm that the area in the immediate vicinity of the power plant is lightly populated. This area is industrialized and contains some suburban population densities compared with the more urban densities visible in Fig. 4. Therefore, if the emergency planning zone for an mPower installation were limited to the site boundary or a small band around the plant, then this site would warrant further investigation.

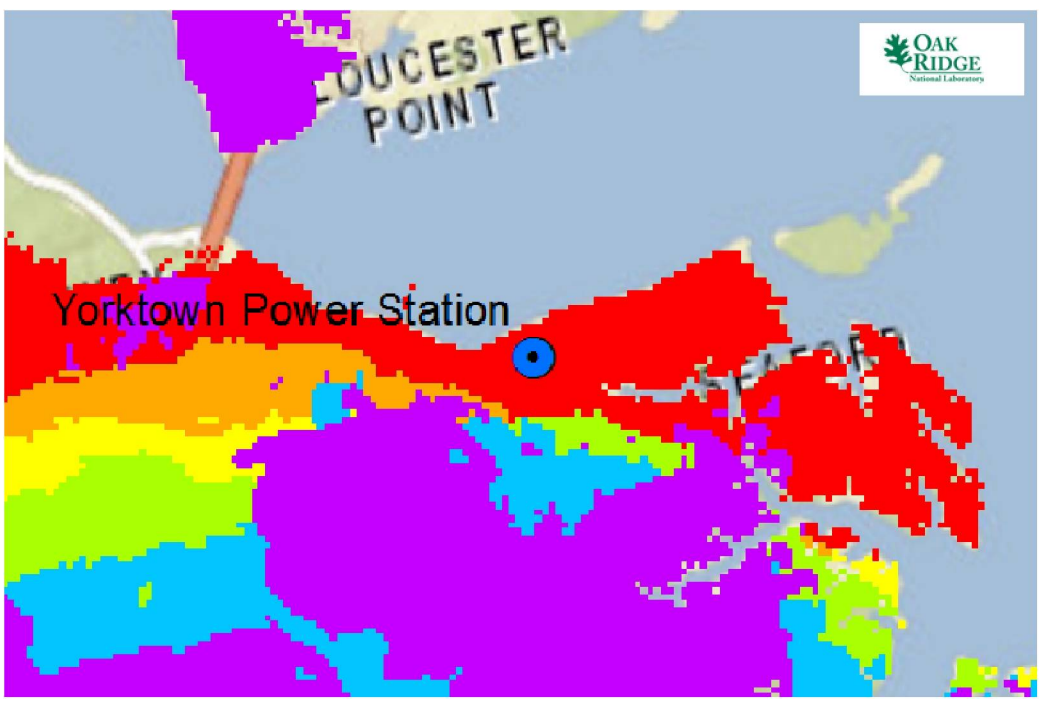

Fig. 16. Cumulative population density calculations for 1, 2, 3, 4, 5, and 10 miles near the Yorktown Power Station.

2.3 ANALYSIS OF FORT STORY

Fort Story is located on Cape Henry at the mouth of the Chesapeake Bay. The site is approximately 5 miles east of the Chesapeake Bay Bridge-Tunnel. Highway access is readily available to the site. Fort Story is part of the Army Transportation Corps Training Center located at Fort Eustis. The fort has been in the possession of the Army as part of the transportation school since 1946. It resides on approximately 1,500 acres, and about half of the site is developed. A power distribution network exists on site, but there is no permanent generation capability on the site.

A satellite view of the Fort Story vicinity is provided in the Google Earth snapshot in Fig. 17. First Landing State Park and Broad Bay border the southern boundary of Fort Story. Both of these areas would limit population growth immediately adjacent to the site.

Fig. 17. Fort Story (Google Earth).

The analysis from Task 2 identified two siting issues: inadequate freshwater stream flow within 20 miles to provide required cooling water makeup, and wetlands and open waters. Areas excluded by these analyses are identified in magenta in Fig. 18. While the area has inadequate freshwater stream flow overall to support closed-cycle cooling water makeup needs, once-through cooling water is readily available from the Atlantic Ocean. As shown, wetlands are a factor in the southeastern portion of the fort. Therefore, the western portion of the fort may be the better location for an underground iPWR.

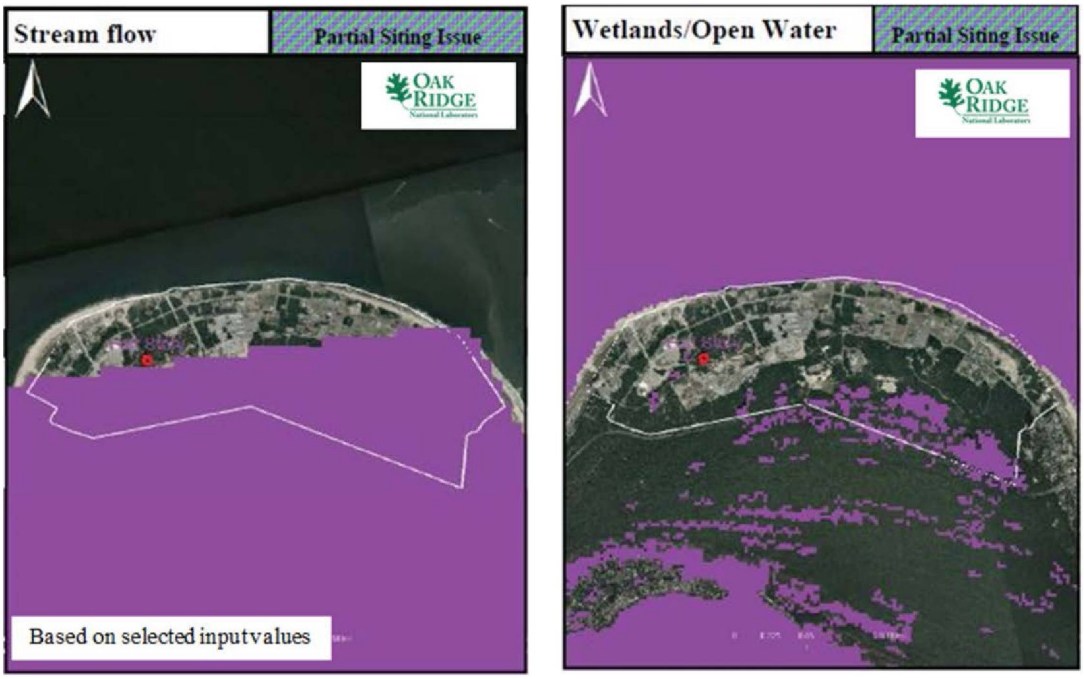

Fig. 18. OR-SAGE siting issues for Fort Story.

Population density data from the LandScan USA database for Fort Story is shown in Fig. 19 (daytime) and Fig. 20 (nighttime). As before, each square cell in the LandScan USA display is 90 × 90 m, which is slightly smaller than the standard OR-SAGE 100 × 100 m cell. Cell color indicates the actual population count (bin) for that square (2 acres). The blue dot in each figure represents a point within the fort, which is outlined by the purple line. The daytime population density in Fig. 19 indicates the daytime workforce at the fort and nearby neighborhoods. Note the contrast with the nighttime population density in Fig. 20, which is largely gray (0 density) on the western portion of the fort. The blue dashed-line square in Fig. 19 and Fig. 20 is a representative 40 acre plot that could accommodate an iPWR. The hypothetical 40 acre plot is intended to provide a size reference relative to the size of the fort and surrounding daytime and nighttime population density. The blue dashed-line square is not intended to project the actual placement of an mPower plant. As shown in Fig. 19, the fort spans approximately 3 miles along an east-west axis.

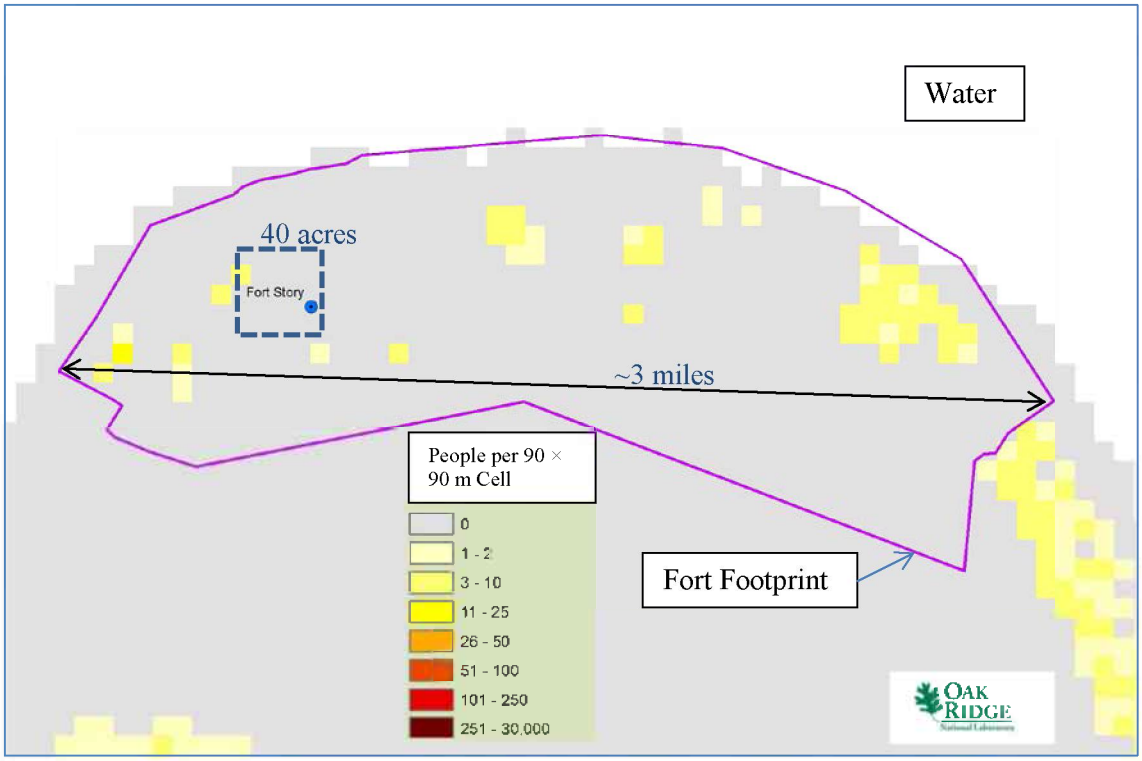

Fig. 19. Landscan™ daytime population near Fort Story.

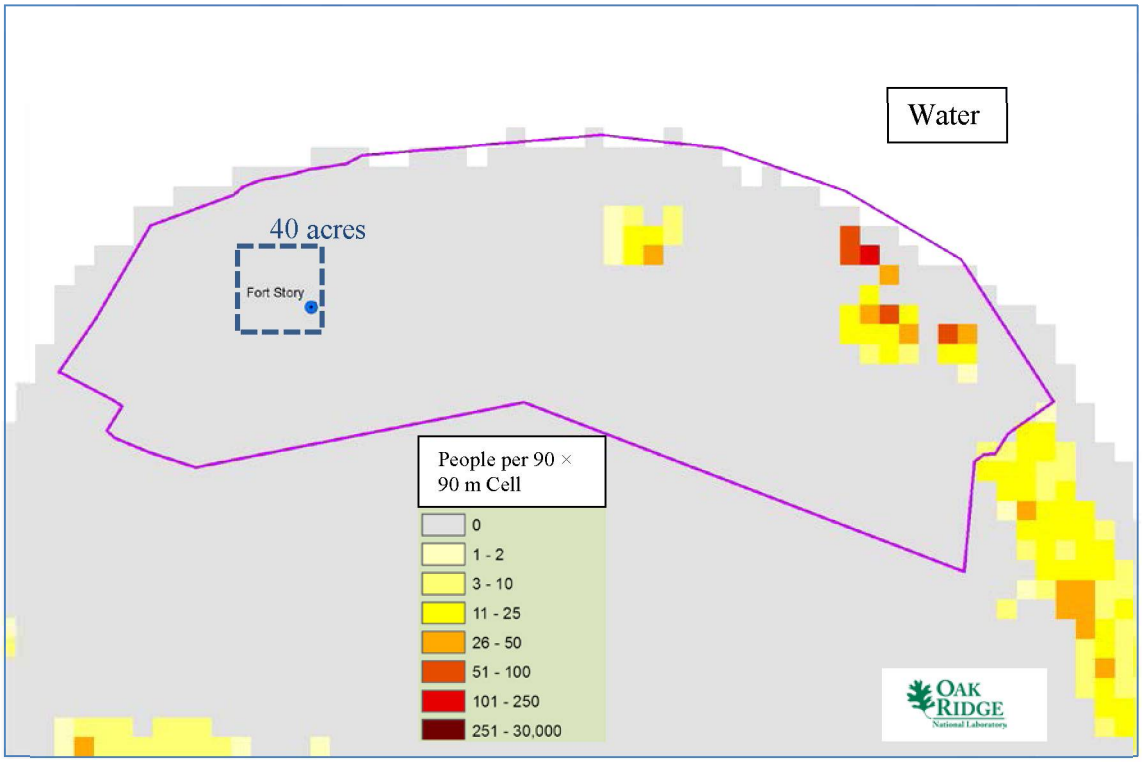

Fig. 20. Landscan™ nighttime population near Fort Story.

A cumulative OR-SAGE calculated population density plot around Fort Story is shown in Fig. 21. (See the discussion regarding the development of the cumulative population density figure in Sect. 2.1.1.) The detail in Fig. 21 is a magnification of the area around Fort Story from Fig. 11. As in Fig. 16 for the Yorktown Power Plant, the individual cells of land in the OR-SAGE database start to become visible in this figure depicting the area around Fort Story. The detail of Fig. 21 shows that various areas of Fort Story are impacted at increasing calculated population densities from 3 miles out to 10 miles. This accounts for the "rainbow" effect in Fig. 21. Looking at this from the opposite perspective, the calculated population density at 2 miles (next lower calculation ring in Fig. 11) around the entire fort is less than 500 people per square mile and for some parts of the fort; the calculated population densities at 3, 4, and 5 miles is less than 500 people per square mile. Using the current ambient population calculation, a utility would likely need to evaluate an EPZ at two miles or less for this location. Expected future population growth would also need to be evaluated.

The plots in Fig. 19 and Fig. 20 confirm that the area in the immediate vicinity of Fort Story is lightly populated. The fort is lightly inhabited and largely surrounded by parkland and suburban population densities, compared with the more urban densities to the south visible in Fig. 4. Adequate space is available to accommodate an iPWR. Therefore, if the EPZ for an mPower installation were limited to the site boundary or a small band around the plant, this site would warrant further investigation.

Fig. 21. Cumulative population density calculations for 1, 2, 3, 4, 5, and 10 miles near Fort Story.

2.4 QUICK LOOK AT THE CHESAPEAKE ENERGY CENTER

Of the six sites that were determined to be the most appropriate for further population density analysis, the Yorktown Power Station and Fort Story were determined to offer the best siting opportunities. However, the Chesapeake Energy Center is in a heavily industrialized area along the Elizabeth River in Chesapeake, Virginia. Along with the river, this industrial area creates a seam in population density (visible in Fig. 11) allowing some potential for siting an mPower facility. The energy center site may be the most limiting of the six sites evaluated.

A satellite view of the Chesapeake Energy Center vicinity is provided in the Google Earth snapshot in Fig. 22. The energy center sits on approximately 150 acres of land, divided by the plant cooling water intake canal. A notional 40 acre site that could site an mPower plant is depicted in red in Fig. 22. Given the limitation of land around the site, there are very limited possibilities for siting an mPower plant at this location.

Day and night population density data from the LandScan USA database for the Chesapeake Energy Center are shown in Fig. 23 and Fig. 24. The blue dot in each figure represents the location of the turbine building. Blue dashed-line boxes provide a visual 40 acre reference for hypothetical iPWR placements. The population associated with the industrialization along the Elizabeth River (blue curve) is visible in Fig. 23, while the residential population is evident in Fig. 24. A number of the business centers along the Elizabeth River are also noted in Fig. 23. The plot shown in Fig. 11 indicates that the Chesapeake Energy Center is impacted at a calculated population density of 2 miles. Looking at this from the opposite perspective, only the calculated population density at 1 mile around the power plant is less than 500 people per square mile. A proposed mPower reactor at this site would require a smaller EPZ than either the Yorktown Power Plant site or the Fort Story site.

Fig. 22. Chesapeake Energy Center (Google Earth).

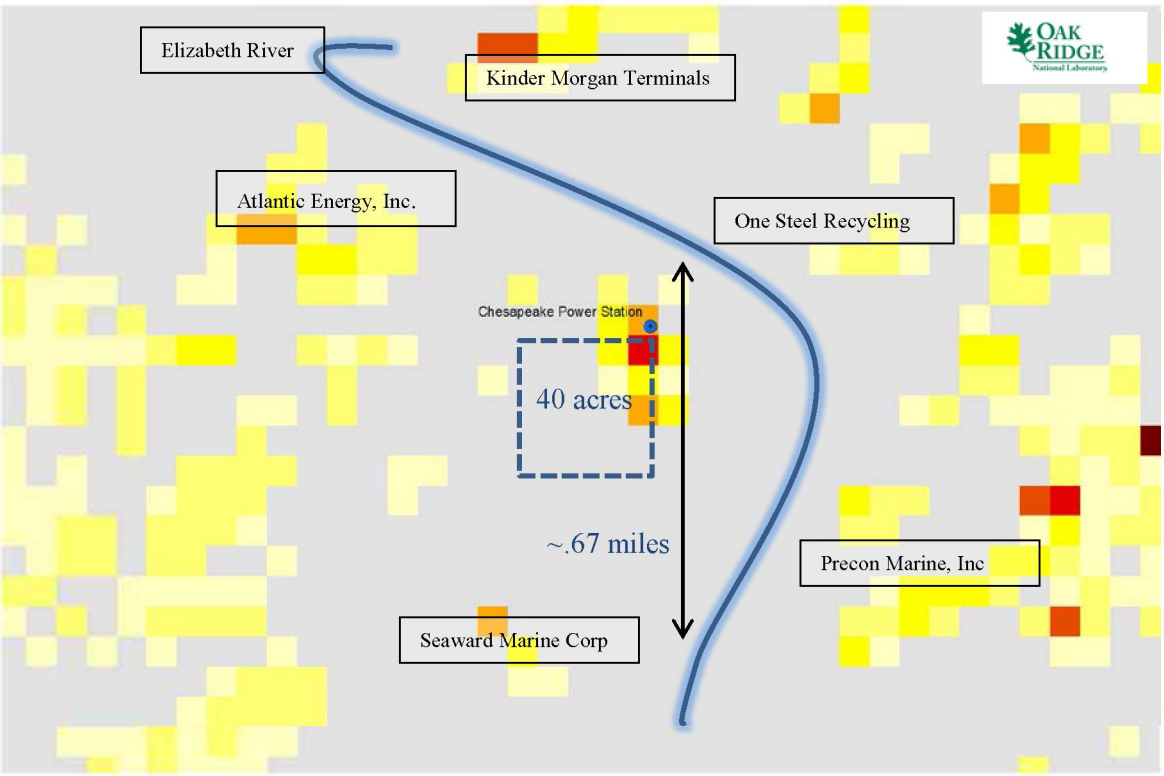

Fig. 23. Landscan™ daytime population near the Chesapeake Energy Center.

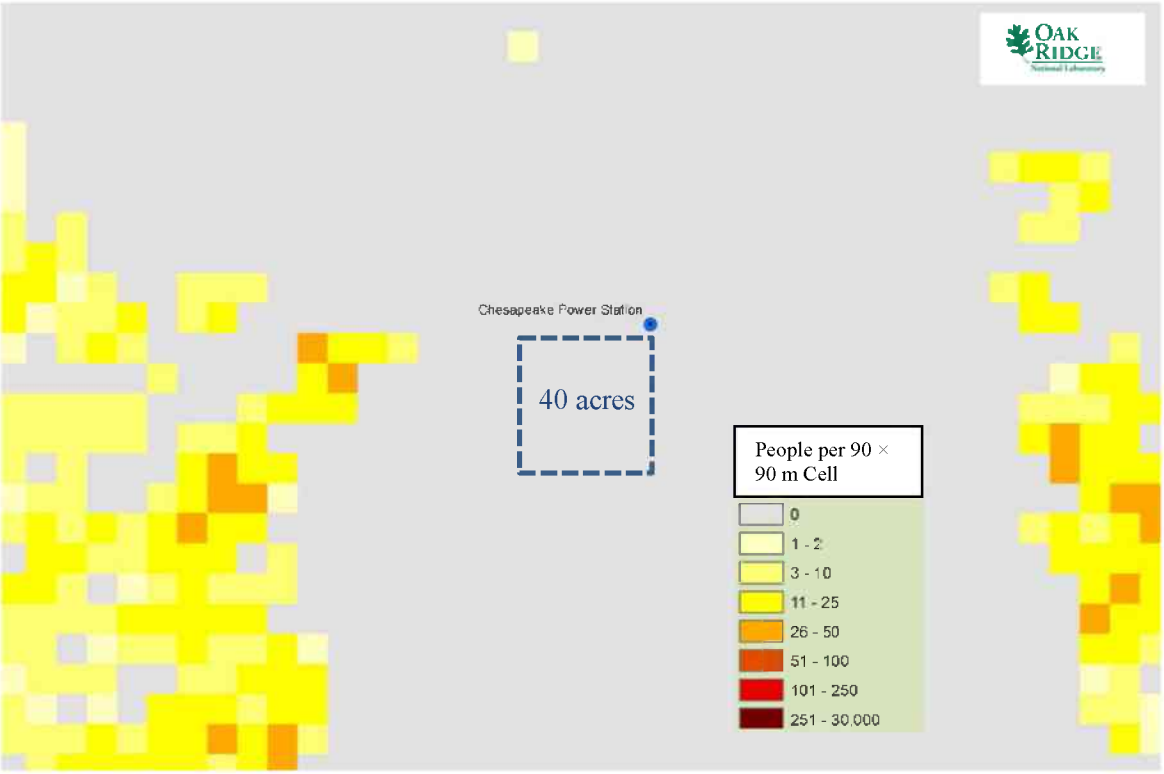

Fig. 24. Landscan™ nighttime population near the Chesapeake Energy Center.

3. SUMMARY

The Hampton Roads, Virginia, area was verified as a potential federal energy cluster in Task 1 of this project. These federal power clusters were identified based upon power usage data, geographical concentration (collocation) of federal agencies, or operation of large federal data centers. Eleven potential sites in the Hampton Roads, Virginia, area were subsequently identified by VSEC as part of Task 2 of this project. The eleven sites were then evaluated using the OR-SAGE tool based on previously developed screening criteria and the application of spatial modeling and GIS. However, the population screening criteria were not initially applied to the site evaluations performed as part of Task 2. For reference purposes, a generalized SMR plant parameter envelope for the B&W Generation dual unit mPower integral design (360 MW(e)) was used for all site evaluations.

A data package and analysis for each site in the sample set was prepared in Task 2, and the results were reported to DOE-NE by letter report[7]. A brief summary of these evaluations is available in Appendix A of this report. The complete set of evaluations is available in the Task 2 letter report.

Based on the Task 2 analyses and the initial evaluation of population density averaged over a radial distance out to 10 miles[§] in Task 3, the Surry Power Station, Camp Peary, and the Yorktown Weapons Station (Naval Weapons Annex) clearly have excellent potential for hosting an iPWR to support federal power needs. All three of these sites have significant space, and none of these sites have significant population issues evaluated out to a distance of 10 miles. Therefore, further evaluation of population density around these three sites did not appear to be useful.

Six additional Task 2 sites were evaluated as favorable for siting an iPWR with either no or minimal siting issues. Again, the Task 2 evaluation did not consider population density as a factor. The initial evaluation of population density in Task 3 indicated that these six sites would be of further interest for a more in-depth look at population density surrounding the sites. These six sites are also closer to the centroid of the Hampton Roads area.

Regional ambient population density analyses based on the NRC Regulatory Guide 4.7[8] approach was conducted at distances of 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, and 10 miles. These plots are shown in Sect. 2.1. Based on this initial screening and the Task 2 results, the Yorktown Power Station and Fort Story were selected for further detailed population density evaluation. Localized LandScan™ plots of these two facilities were evaluated.

The area in the immediate vicinity of the Yorktown Power Station is lightly populated. The area is industrialized and contains suburban population densities compared with the more urban densities observed in nearby Hampton and Newport News. The detail of Fig. 16 shows that the Yorktown Power Station is only impacted at a calculated population density of 10 miles. In other words, the calculated population density at 5 miles around the power plant is less than 500 people per square mile. Using the current ambient population calculation, a utility would likely need to evaluate an EPZ at five miles or less for this location to avoid population density challenges using the guidance provided in NRC Regulatory Guide 4.7. Expected future population growth would also need to be evaluated. Therefore, if the EPZ for an mPower installation were limited to the site boundary or a small band (5 miles) around the plant, then this site would warrant further investigation.

The area in the immediate vicinity of Fort Story is also lightly populated. The fort is lightly inhabited and is largely surrounded by parkland and suburban population densities, compared with the more urban densities in Norfolk to the south. The calculated population density at 2 miles around the entire fort is less than 500 people per square mile. For some parts of the fort, the calculated population densities at 3, 4, and

[§]Note that 10 miles is half the recommended distance of 20 miles in NRC Regulatory Guide 4.7[8] for evaluating population density. This was done intentionally to acknowledge the potential for SMRs to have a smaller source term compared to current light-water reactors. The NRC has not provided siting guidance tailored specifically for SMRs.

5 miles are less than 500 people per square mile. Using the current ambient population calculation, a utility would likely need to evaluate an EPZ at two miles or less for this location. Expected future population growth would also need to be evaluated. Adequate space is available to accommodate an iPWR at the fort. Therefore, if the EPZ for an mPower installation were limited to the site boundary or a small band (2 miles) around the plant, then this site would warrant further investigation.

The Chesapeake Energy Center appeared to be the most limiting site of the six sites reviewed in Task 3. While the calculated population density at 1 mile around the energy center is less than 500 people per square mile, a proposed mPower reactor at this site would require a much smaller EPZ than either the Yorktown Power Plant site or the Fort Story site but would still be possible if set at one mile or less (site boundary). Based solely on the population density review where the existing population density is less than 500 people per square mile, a plume exposure pathway EPZ summary (or the low population zone boundary) of each site is shown in Table 3. Each of these six sites has the potential for favorable iPWR siting based on initial OR-SAGE review and population density analysis.[**] This is in addition to the Surry Power Station, Camp Peary, and the Yorktown Weapons Station (Naval Weapons Annex), which have no population density issues at a calculated population density of 10 miles.

Table 3. Summary of six evaluated sites in Task 3

Proposed site	Recommended EPZ based on current population density[a]
Chesapeake Energy Center	1 mile
Craney Island	1 mile
Fort Story	2-5 miles
Langley Air Force Base	2 miles
Norfolk Naval Base	3 miles
Yorktown Power Station	5 miles

[a]Assumes optimal siting at facility.

Based on guidance provided by Regulatory Guide 4.7 on siting, all six of the sites considered in Task 3 and listed in Table 3 above would be eliminated from consideration based on population density out to 20 miles. Furthermore, all six sites would be eliminated using a more favorable population density calculation at 10 miles, which correlates to the plume exposure pathway EPZ. However, by conducting the initial screen without considering population density (Task 2) and then applying more sophisticated population tools for analysis of select candidate sites, additional options for siting iPWRs closer to population centers is feasible. This is dependent on iPWR vendors demonstrating that the plume exposure pathway EPZ can be established at a distance less than the standard 10 miles.

The overall objective of this research project is to support DOE-NE in evaluating future electrical generation deployment options for iPWRs in areas with significant energy demand from the federal sector. There are several sites within the Hampton Roads area that have potential for favorable deployment of an iPWR to provide a means of meeting federal clean energy goals. Similar methodology can be applied to other federal energy cluster locations.

[**]SMR applicant would be required to make the safety case with the NRC regarding appropriate plume exposure pathway EPZ.

4. REFERENCES

1. G. T. Mays, T. J. Harrison, and O. A. Omitaomu, *Preliminary Report on Siting Evaluation Tool for Commercial Nuclear Power Plants Developed by Oak Ridge National Laboratory*, LTR/DOE-NE/Siting-2010/002, November 2010.
2. R. J. Belles, G. T. Mays, O. A. Omitaomu, and W. P. Poore, *Updated Application of Spatial Data Modeling and Geographical Information Systems (GIS) for Identification of Potential Siting Options for Small Modular Reactors*, ORNL/TM-2012/403, Oak Ridge National Laboratory, Oak Ridge, TN, September 2012.
3. G. T. Mays, R. J. Belles, O. A. Omitaomu, et al., *Application of Spatial Data Modeling and Geographical Information Systems (GIS) for Identification of Potential Siting Options for Various Electrical Generation Sources*, ORNL/TM-2011/157/R1, Oak Ridge National Laboratory, Oak Ridge, TN, May 2012.
4. R. J. Belles, G. T. Mays, O. A. Omitaomu, and W. P. Poore, *Evaluation of Suitability of Selected Set of Coal Plant Sites for Repowering with Small Modular Reactors*, ORNL/TM-2013/109, Oak Ridge National Laboratory, Oak Ridge, TN, March 2013.
5. W. P. Poore, R. J. Belles, G. T. Mays, and O. A. Omitaomu, *Evaluation of Suitability of Selected Set of Department of Defense Military Bases and Department of Energy Facilities for Siting a Small Modular Reactor*, ORNL/TM-2013/118, Oak Ridge National Laboratory, Oak Ridge, TN, March 2013.
6. R. J. Belles, G. T. Mays, O. A. Omitaomu, and W. P. Poore, *Identification of Selected Areas to Support Federal Clean Energy Goals Using Small Modular Reactors*, ORNL/TM-2013/578, Oak Ridge National Laboratory, Oak Ridge, TN, December 2013.
7. R. J. Belles, T. J. Harrison, and O. A. Omitaomu, *Evaluation of Proposed Hampton Roads Area Sites for Using Small Modular Reactors to Support Federal Clean Energy Goals*, ORNL/LTR-2014/155, Oak Ridge National Laboratory, Oak Ridge, TN, April 2014.
8. Regulatory Guide 4.7, *General Site Suitability Criteria for Nuclear Power Stations*, US Nuclear Regulatory Commission, April 1998.

APPENDIX A. Summary of Site Evaluations for Camp Peary, the Surry Nuclear Power Station, and the Yorktown Naval Weapons Station

APPENDIX A. SUMMARY OF SITE EVALUATIONS FOR CAMP PEARY, THE SURRY NUCLEAR POWER STATION, AND THE YORKTOWN NAVAL WEAPONS STATION

A.1 CAMP PEARY

A.1.1 Description

Camp Peary is located in York County, Virginia. As shown in Fig. A.1, the site is located between the York River and Interstate 64. The camp center is approximately 4 miles north of Colonial Williamsburg. Rail, barge, and interstate access are all readily available to the site. An airstrip is also available on the site.

Fig. A.1. Camp Peary location map.

Camp Peary was established during World War II by the Navy as a Seabee training base. It is currently used by various intelligence services for training. The camp consists of more than 9000 acres, most of which are in a natural state.

Camp Peary is roughly 11 miles from the Surry Nuclear Power Station across the York River and 32 miles from the Norfolk Naval Base in the central part of the region of interest.

The permanent population within 1 mile of the camp is approximately 1600 people, yielding a population density of approximately 500 people per square mile. The permanent population within 10 miles of the plant is approximately 223,000 people, yielding a population density of about 700 people per square mile. There is some single family housing on the camp property, but otherwise, housing appears to be limited in the area. Two schools are immediately south of Interstate 64 from the camp property.

A.1.2 Composite Map

Based on analyses performed previously using a selected set of input parameters, a composite map of SMR siting challenges to Camp Peary is depicted in Fig. A.2. As shown (independent of population), half of the property outlined is immediately favorable for siting an iPWR.

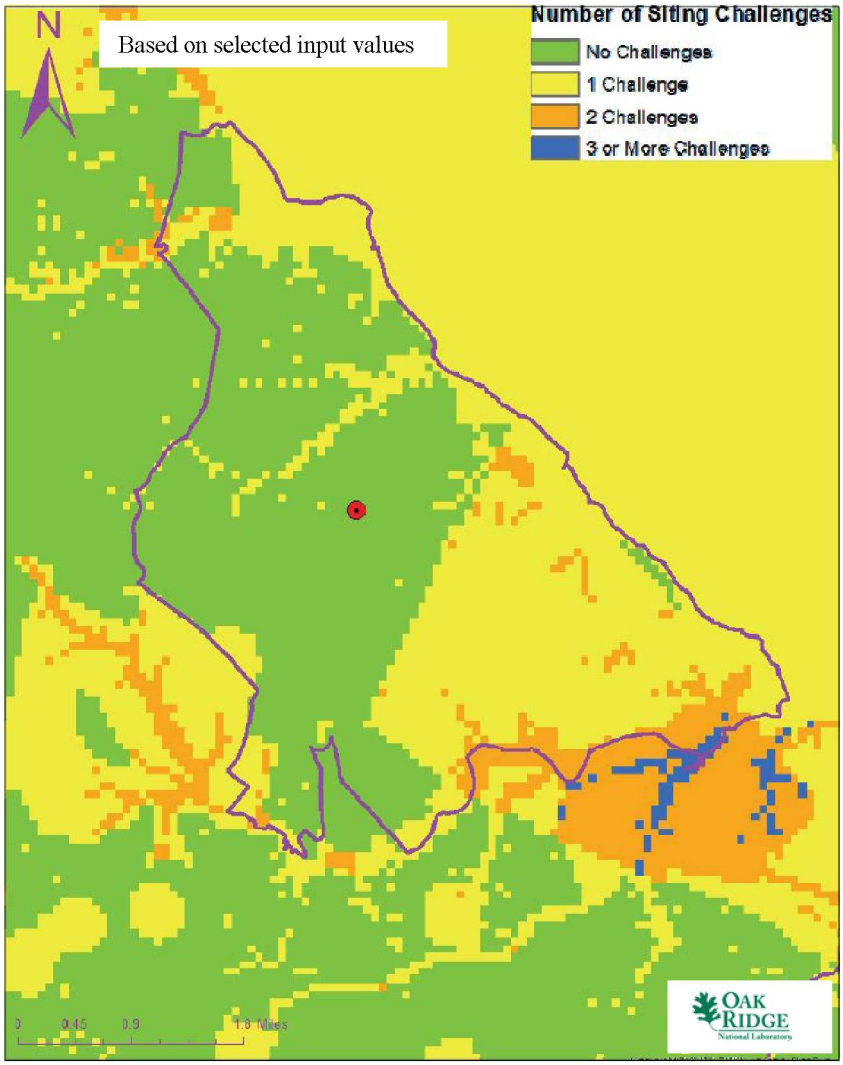

Fig. A.2. Camp Peary composite map.

A.1.3 Site Population Evaluation

There are public parks and green space recreation areas on the three land-based sides of the camp. These include the York River State Park to the north, the Walter Mill Reservoir to the west, and Queens Creek to the south. The Colonial National Historic parkway also runs near the southeastern edge of the property. The York River flows along the remaining face of the property. A Naval Supply Center is adjacent to Camp Peary to the southeast on the York River. Therefore, the potential for population growth in the immediate vicinity of the camp property is limited.

A.2 SURRY NUCLEAR POWER STATION

A.2.1 Description

The Surry Nuclear Power Station is located in Surry County, Virginia. As shown in Fig. A.3, the site is located on the southern bank of the James River due south of Colonial Williamsburg. The station center is approximately 7 miles south of Colonial Williamsburg. Barge access is readily available to the site, and rail access is within 4 miles.

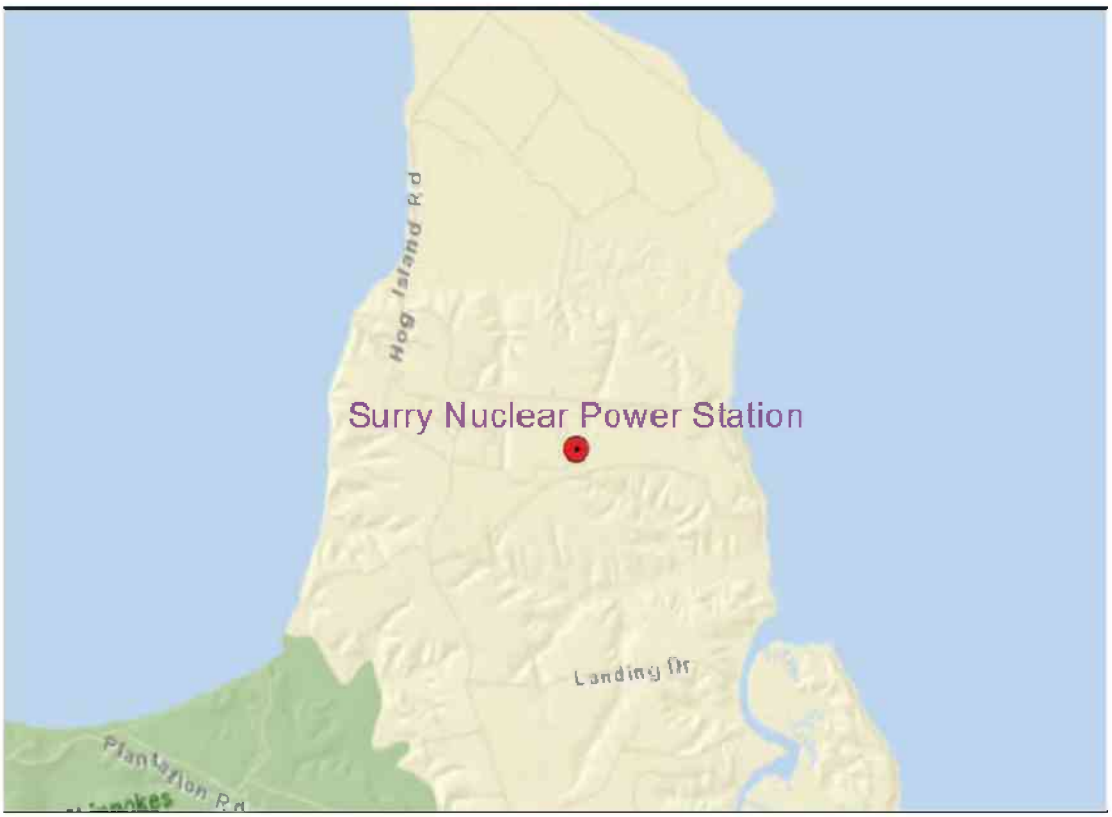

Fig. A.3. Surry Nuclear Power Station location map.

The Surry Nuclear Power Station generates 1676 MW(e) from two PWRs. Unit 1 was commissioned in 1972, and Unit 2 was commissioned in 1973. The plant resides on approximately 1000 acres, though Dominion Resources has access to an additional 750 acres adjacent to the Surry site.

The station is roughly 25 miles northwest of the Norfolk Naval Base in the central part of the region of interest.

The permanent population within 1 mile of the power plant is approximately 1,300 people, yielding a population density of approximately 400 people per square mile. The permanent population within 10 miles of the plant is approximately 315,000 people, yielding a population density of about 1,000 people per square mile. The peninsula of land occupied by the Surry Nuclear Power Station is largely undeveloped and contains limited housing.

A.2.2 Composite Map

A composite map of SMR siting challenges to the Surry Nuclear Power Station is depicted in Fig. A.4. As shown (independent of population), most of the property has a single screening issue for siting an iPWR.

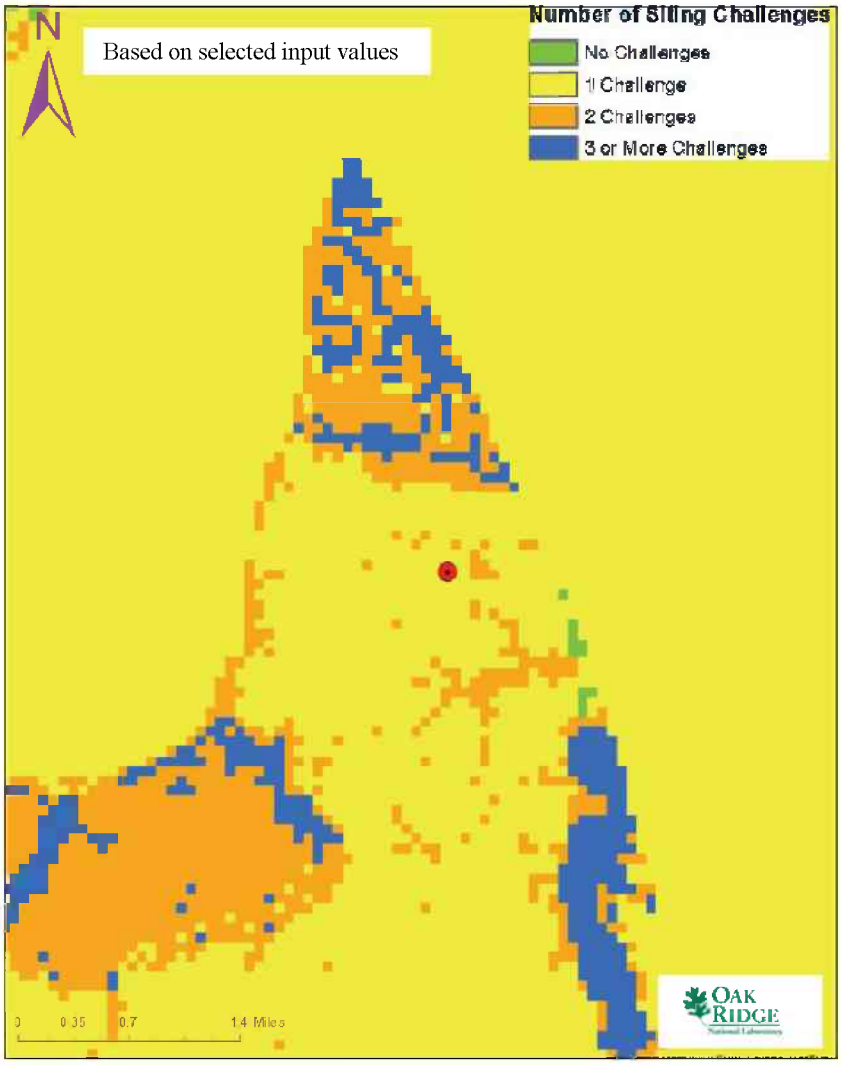

Fig. A.4. Surry Nuclear Power Station composite map.

A.2.3 Site Population Evaluation

The composite map above shows that the peninsula occupied by the Surry Nuclear Power Station has a single screening issue. There is a moderate to high probability for a landslide hazard on the peninsula. Landslide hazards, including sink holes, are based on a probabilistic evaluation by the US Geological Survey (USGS) and not on site-specific geological analyses. Given that Dominion Resources performed due diligence for the Surry site in the initial environmental analysis of the area and that the Surry site has been occupied and in operation since the early 1970s without incidence of landslides, this does not appear to be a factor limiting further use of the site.

The tip of the peninsula is protected and designated as the Hog Island State Waterfowl Refuge. In addition, the Surry County Chippokes Plantation State Park is just south of the Surry plant. The James River, parkland, and largely undeveloped rural land surround the plant boundary. These areas are not likely to be developed much further in the future. Therefore, the potential for population growth in the immediate vicinity of the plant property is limited.

A.3 YORKTOWN NAVAL WEAPONS STATION

A.3.1 Description

The Yorktown Naval Weapons Station is located principally in York County, Virginia. As shown in Fig. A.5, the site is located between the York River, the Colonial Parkway, and Interstate 64. The station center is approximately 6.75 miles southeast of Colonial Williamsburg. Rail, barge, and interstate access are all readily available to the site. A helipad is also available on the site.

Fig. A.5. Yorktown Naval Weapons Station location map.

The Yorktown Naval Weapons Station and Cheatham Annex accommodate 25 resident commands. The main area of the base has been in the possession of the Navy since 1943. The station, including the Cheatham Annex, consists of more than 13,000 acres, much of which is in a natural state.

The permanent population within 1 mile of the station is approximately 2000 people, yielding a population density of approximately 600 people per square mile. The permanent population within 10 miles of the plant is approximately 360,500 people, yielding a population density of about 1,150 people per square mile. There is some single family housing on the western border of the station property, but otherwise, there appears to be limited housing in the area. Only 457 housing units are available on the station property. There is also a waterpark and shopping center to the west of the property. Parkland associated with the Yorktown battlefield and the Newport News park system exists to the southeast of the station property.

A.3.2 Composite Map

A composite map of SMR siting challenges to the weapons station is depicted in Fig. A.6. As shown (independent of population), half of the property outlined is immediately favorable for siting an iPWR.

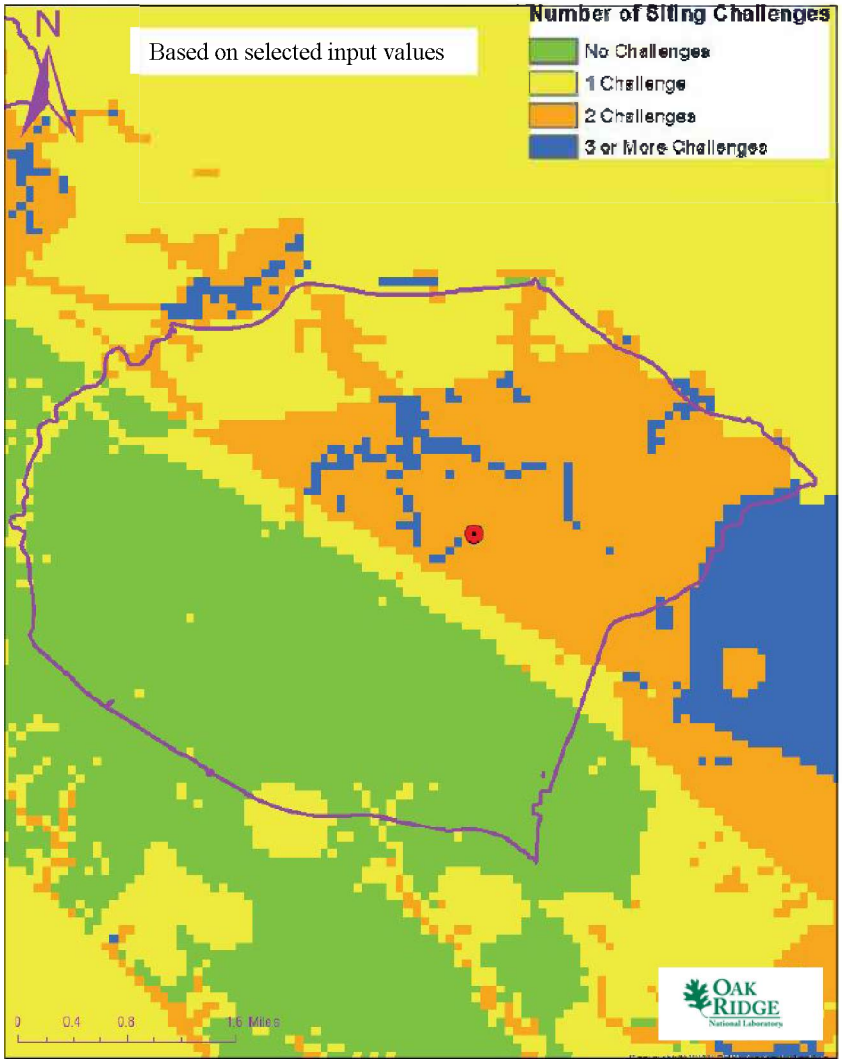

Fig. A.6. Yorktown Naval Weapons Station composite map.

A.3.3 Site Population Evaluation

The composite map above shows that the southern portion of the Yorktown Naval Weapons Station site is favorable for siting an iPWR. The northern portion of the site has a moderate to high probability for a landslide hazard (along the shore of the York River). Landslide hazards, including sink holes, are based on a probabilistic evaluation by the USGS. Therefore, the northern section of the site may also be favorable for siting an iPWR, pending further onsite geological evaluation.

There are government lands, public parks, and green space recreation areas on two of the three land-based sides of the station. These include Queens Creek and the Cheatham Naval Supply Center to the northwest and the Yorktown battlefield area to the southeast. Across Interstate 64 to the southwest, there are some housing subdivisions. However, much of this area contains green space associated with a plantation, a golf course, a water reprocessing facility, and a jail facility. In addition, there are several large distribution warehouse facilities. These areas are not likely to be developed much further in the future. The Colonial National Historic parkway and the York River bound the remaining edge of the property. Therefore, the potential for population growth in the immediate vicinity of the station property is limited.

APPENDIX B. Summary of Site Evaluations for Task 3 Site Sample Set

APPENDIX B. SUMMARY OF SITE EVALUATIONS FOR TASK 3 SITE SAMPLE SET

B.1 CHESAPEAKE ENERGY CENTER

B.1.1 Description

The Chesapeake Power Station is located in the city of Chesapeake, Virginia. As shown in Fig. B.1, the land is located on the Elizabeth River. Rail, barge, and interstate access are all readily available to the site.

Fig. B.1. Chesapeake Power Station location map.

Chesapeake Power Station is a four unit coal power plant. The four units total 595 MW and were built in stages from 1953 through 1962. The site also includes 122 MW of natural gas turbines, bringing the total power generation capacity to 717 MW. The coal plants are scheduled for closure by 2015.

The permanent population within 1 mile of the power station is approximately 10,000 people[††], yielding a population density of approximately 3,100 people per square mile. The permanent population within 10 miles of the plant is approximately 1,200,000 people, yielding a population density of about 3,800 people per square mile.

B.1.2 Composite Map

Based on analyses performed previously using a selected set of input parameters, a composite map of SMR siting challenges to Chesapeake Power Station is depicted in Fig. B.2. As shown (independent of population), most of the site outlined is favorable for siting an iPWR.

[††] All population figures in Appendix B represent gross population values and do not reflect directional population density.

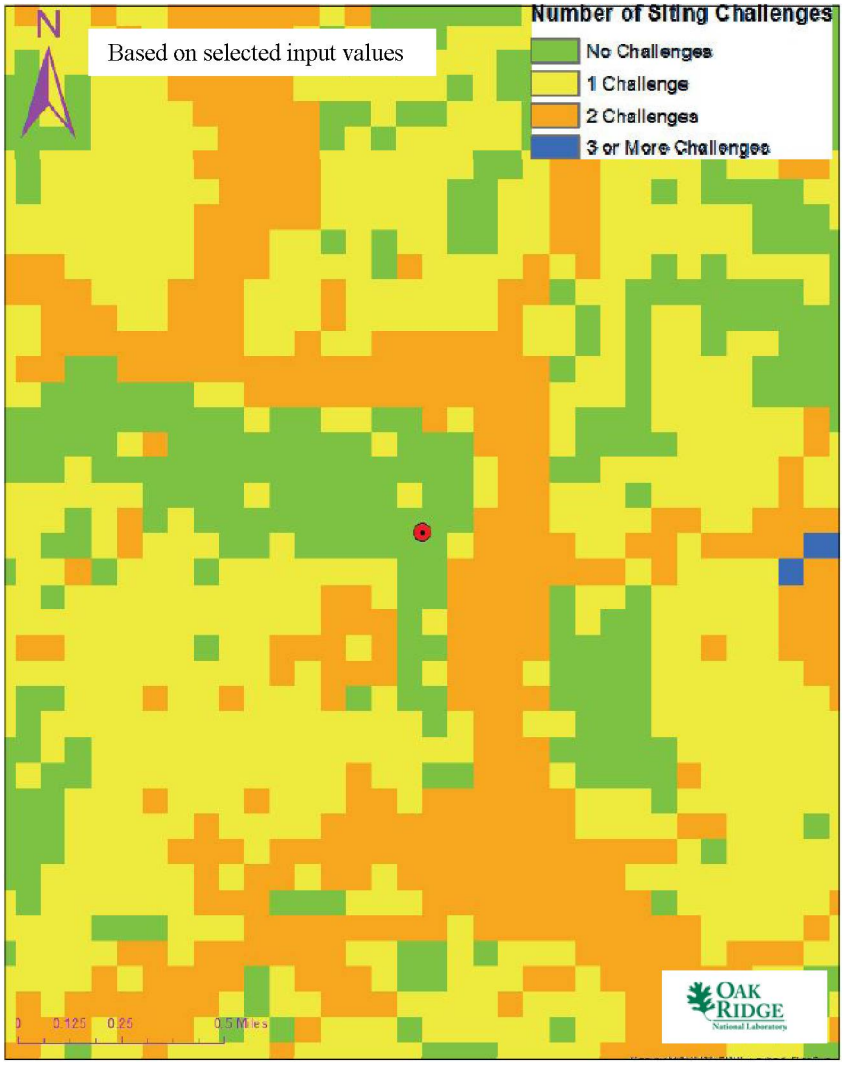

Fig. B.2. Chesapeake Power Station composite map.

B.1.3 Site Population Evaluation

The Elizabeth River bounds the site on the north and east, and the city of Chesapeake sits directly east across the river. Residential neighborhoods exist along the western boundary, and Deep Creek forms its southern boundary. As shown in Fig. 3, the site is well within an area evaluated at 500 people per square mile within ten miles. However, the immediate area is very industrial, and Fig. 4 confirms that the population is less dense near the plant site.

B.2 CRANEY ISLAND

B.2.1 Description

Craney Island is located in the city of Portsmouth, Virginia. As shown in Fig. B.3, the land is located on the Elizabeth River. Rail, barge, and interstate access are all readily available to the site.

Fig. B.3. Craney Island location map.

Craney Island is an industrial area operated by the US Army Corps of Engineers and is used for placement of dredged materials. It sits adjacent to a US Navy refueling depot. The site consists of more than 1700 acres, most of which are in an unimproved state.

The permanent population within 1 mile of the camp is approximately 6,500 people[‡‡], yielding a population density of approximately 2,000 people per square mile. The permanent population within 10 miles of the plant is approximately 1,100,000 people, yielding a population density of about 3,500 people per square mile.

B.2.2 Composite Map

Based on analyses performed previously using a selected set of input parameters, a composite map of SMR siting challenges to Craney Island is depicted in Fig. B.4. As shown (independent of population), half of the property outlined shows no challenges for siting an iPWR. Following this map are maps of the individual SMR siting criteria based on selected input values.

[‡‡] All population figures in Appendix B represent gross population values and do not reflect directional population density.

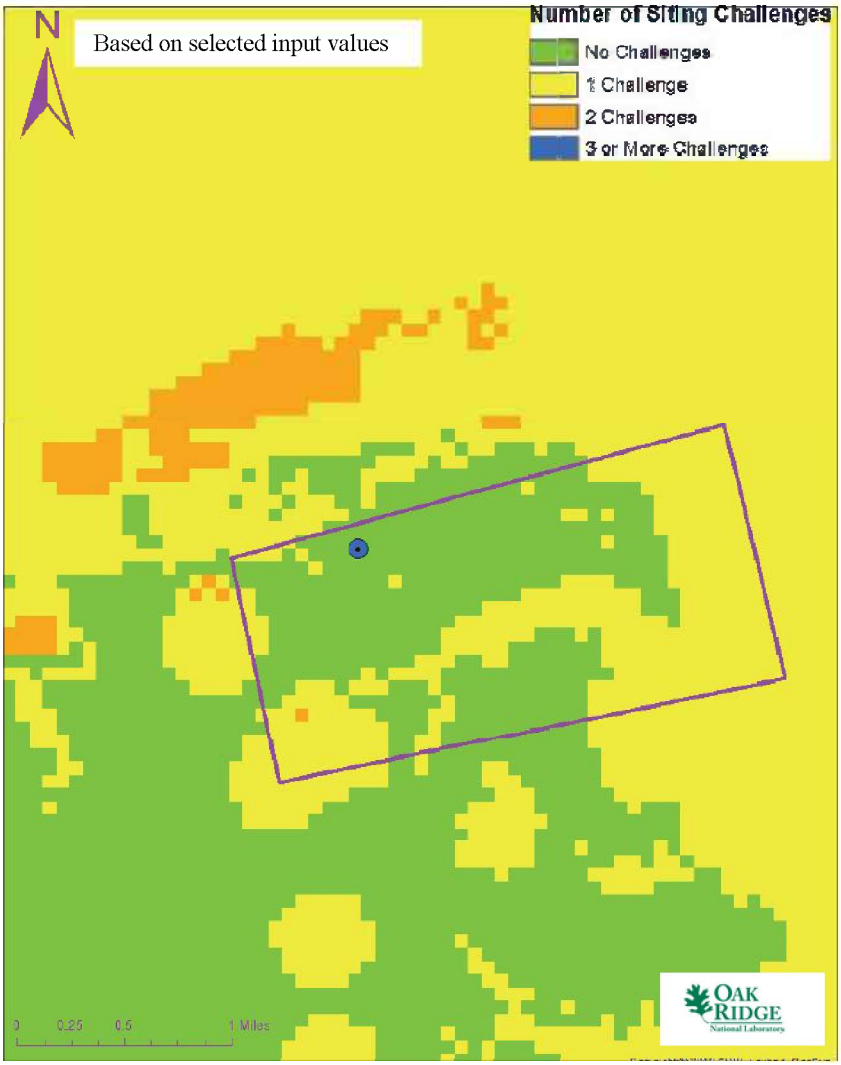

Fig. B.4. Craney Island composite map.

B.2.3 Site Population Evaluation

The composite map above shows that the majority of the Craney Island site is predominantly favorable for siting an iPWR. The eastern portion and some central portions of the site have an issue with wetlands/open water, and there are some protected lands (schools) along the southwest border.

In addition to schools, there is significant housing to the west of the site and across the Elizabeth River from the site. As shown in Fig. 3, the site is within an area evaluated at 500 people per square mile within ten miles.

B.3 FORT STORY

B.3.1 Description

Fort Story is located within the city of Virginia Beach, Virginia, at Cape Henry. As shown in Fig. B.5, the site is located just north of US Highway 60 at the mouth of the Chesapeake Bay. The site is approximately 5 miles east of the Chesapeake Bay Bridge-Tunnel. Highway access is readily available to the site.

Fig. B.5. Fort Story location map.

Fort Story is part of the Army Transportation Corps Training Center located at Fort Eustis. The fort has been in the possession of the Army as part of the transportation school since 1946. The fort resides on approximately 1,500 acres; about half of the area developed. Fort Story is approximately 35 miles southeast of Fort Eustis. Unlike Fort Eustis, there is no pier or rail head available at Fort Story. The Department of Defense uses Fort Story to train on amphibious landings and ship-to-shore transfer of cargo. There are 2,500 soldiers and family members living onsite.

The permanent population within 1 mile of the fort is approximately 3,000 people[§§], yielding a population density of approximately 950 people per square mile. The permanent population within 10 miles of the plant is approximately 720,000 people, yielding a population density of about 2,300 people per square mile. First Landing State Park and Broad Bay provide a significant buffer along the southern boundary of Fort Story.

[§§] All population figures in Appendix B represent gross population values and do not reflect directional population density.

B.3.2 Composite Map

A composite map of SMR siting challenges to Fort Story is depicted in Fig. B.6. As shown, (independent of population) most of the property has a single screening issue for siting an iPWR.

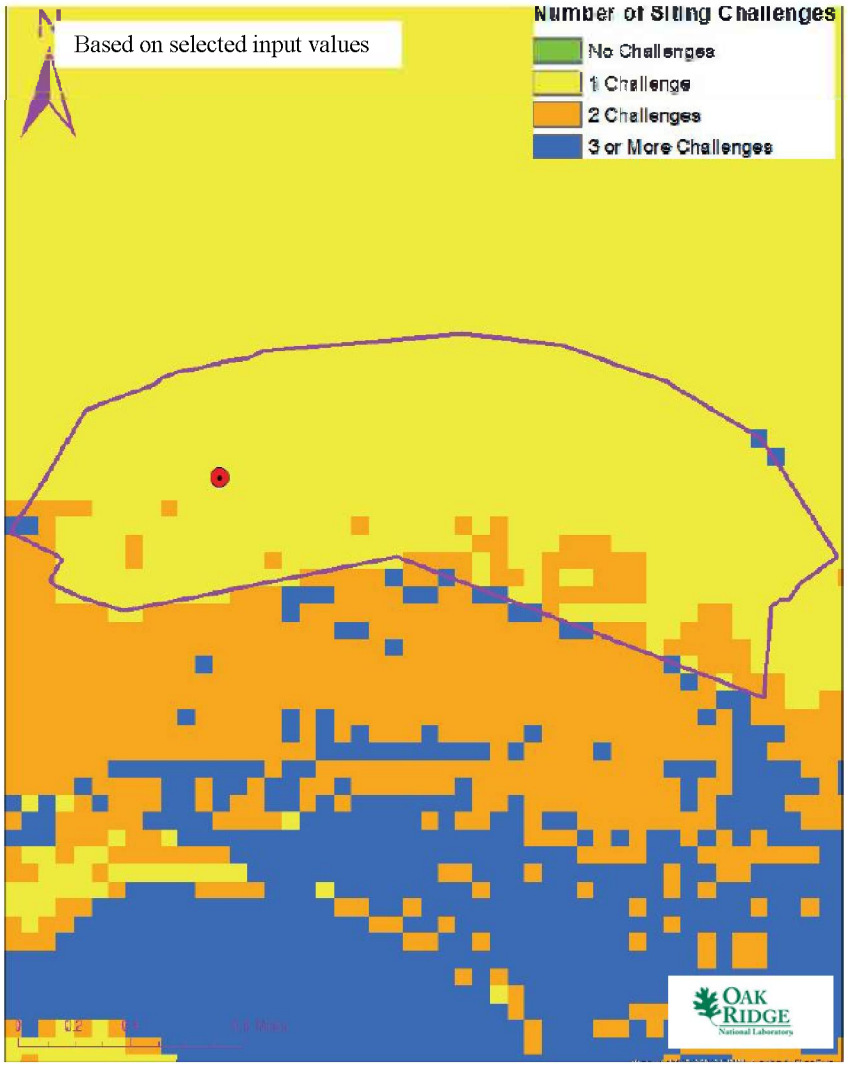

Fig. B.6. Fort Story composite map.

B.3.3 Site Population Evaluation

The composite map above shows that Cape Henry has a single screening issue: a lack of adequate freshwater for makeup to a closed cycle cooling system. Other cooling options are available based on the site location at the mouth of the Chesapeake Bay.

First Landing State Park and Broad Bay border the southern boundary of Fort Story. Both of these areas would limit population growth immediately adjacent to the site. As shown in Fig. 3, the site is at the outside edge of an area evaluated at 500 people per square mile within ten miles. While the overall population density may be high in the general area; the population density at a localized level is low and likely to remain low. This is confirmed by Fig. 4.

B.4 Langley Air Force Base

B.4.1 Description

Langley Air Force Base is located within Hampton, Virginia. The site is surrounded by Poquoson to the north and Newport News to the east. As shown in Fig. B.7, the site is located off the Back River facing the Chesapeake Bay. Rail, barge, and interstate access are all readily available to the site. A substantial runway is also available on the site.

Fig. B.7. Langley Air Force Base location map.

Langley Air Force Base is an Air Force installation; it is part of Joint Base Langley-Eustis. The base has been in the possession of the military since 1916 and is the home of the Air Combat Command, but it also accommodates other tenant commands. In addition, the National Aeronautics and Space Administration (NASA) Langley Research Center abuts the base to the west. Langley Air Force Base resides on more than 3,000 acres, much of which are developed. There is undeveloped area in the northern portion of the base, away from and perpendicular to the runway. Approximately 25,000 airmen, family members and civilian employees work or live onsite

The permanent population within 1 mile of the base is approximately 5,000 people[***], yielding a population density of approximately 1,600 people per square mile. The permanent population within 10 miles of the plant is approximately 750,000 people, yielding a population density of about 2,400 people per square mile. There is housing on site and in the surrounding communities. There are also numerous schools and business centers adjacent to the property.

[***] All population figures in Appendix B represent gross population values and do not reflect directional population density.

B.4.2 Composite Map

A composite map of SMR siting challenges to the base is depicted in Fig. B.8. As shown (independent of population), most of the property has a single screening issue for siting an iPWR.

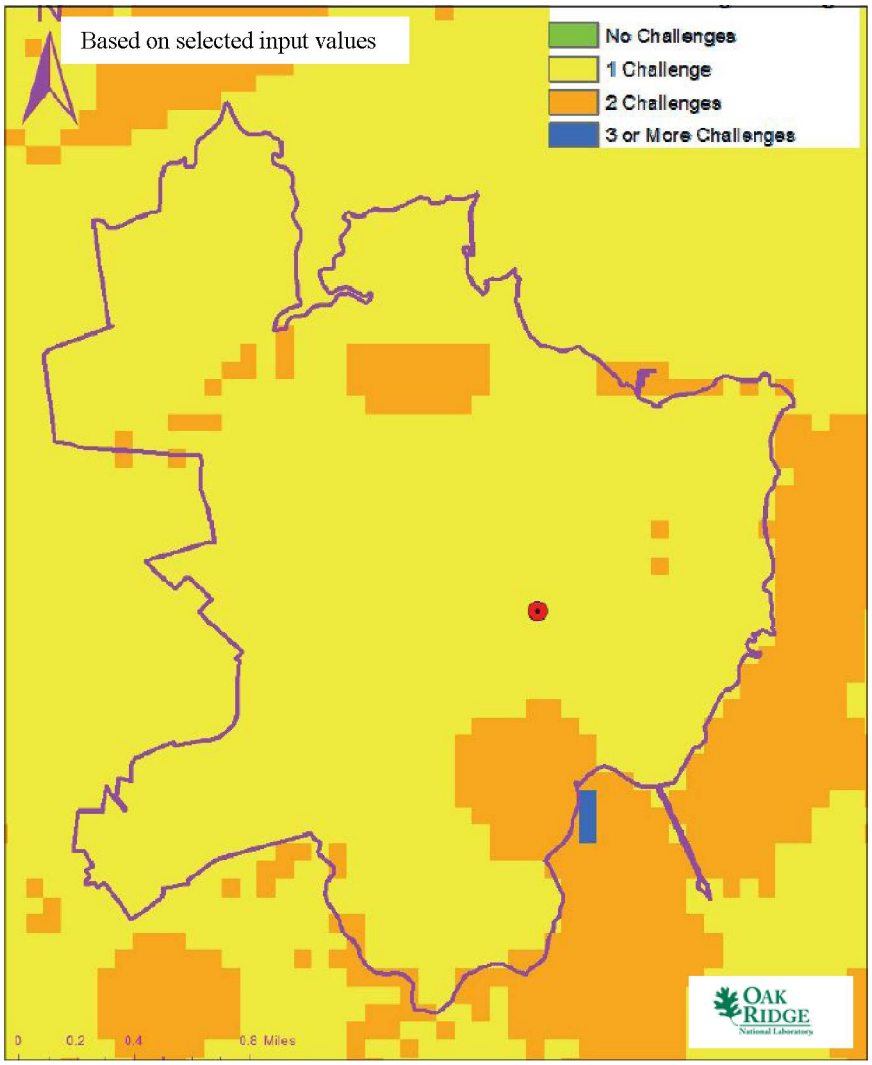

Fig. B.8. Langley Air Force Base composite map.

B.4.3 Site Population Evaluation

The composite map above shows that Langley Air Force Base site has a single screening issue. There is an indicated lack of fresh water makeup to support a closed cycle cooling water system for an iPWR. Given the site's proximity to the Back River, the Chesapeake Bay, and recycled water from population centers, there are clearly other cooling options for the site.

The eastern circumference of the base is surrounded by branches of the Back River and the NASA Langley Research Center bonds the western border of the base. Both of these factors would limit population growth in the immediate vicinity of the base. As shown in Fig. 3, the site is within an area evaluated at 500 people per square mile within ten miles. However, the northern portion of the base is near the edge of the area evaluated at greater than 500 people per square mile within ten miles. The population is lighter in the immediate vicinity of the power station, as confirmed by Fig. 4.

B.5 NORFOLK NAVAL BASE (NAVAL STATION NORFOLK)

B.5.1 Location Detail

Norfolk Naval Base is located in the city of Norfolk, Virginia. As shown in Fig. B.9, the site is located between the mouth of the James River and Interstate 64. Rail, barge, and interstate access are all readily available to the site.

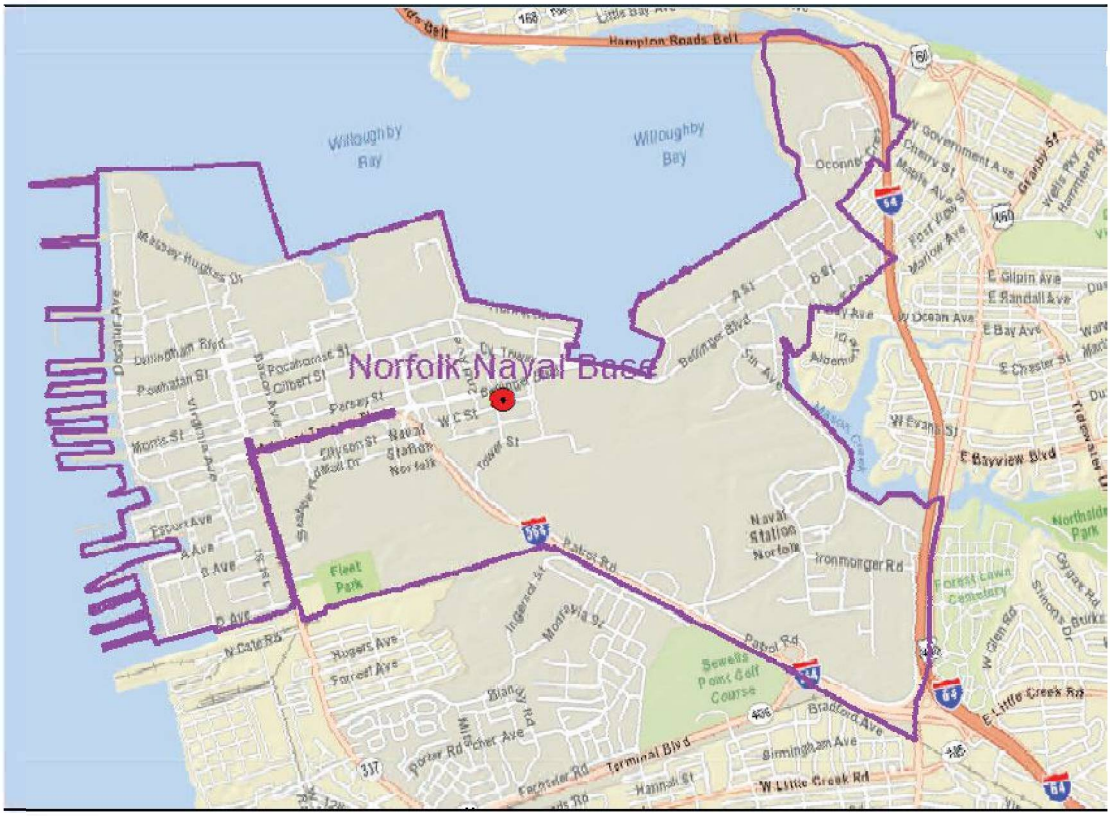

Fig. B.9. Norfolk Naval Base location map.

Norfolk Naval Base was established near the end of World War I by the Navy as a combined training center, air station, hospital, and submarine station. Its primary mission is Atlantic Fleet support. The base consists of about 3,400 acres on Sewells Point and is the world`s largest naval station.

The permanent population within 1 mile of the base is approximately 20,000 people[†††], yielding a population density of approximately 6,400 people per square mile. The permanent population within 10 miles of the plant is approximately 1,200,000 people, yielding a population density of about 3,800 people per square mile.

B.5.2 Composite Map

A composite map of SMR siting challenges to Norfolk Naval Base is depicted in Fig. B.10. As shown (independent of population), the pier area of the base is immediately favorable for siting an iPWR.

[†††] All population figures in Appendix B represent gross population values and do not reflect directional population density.

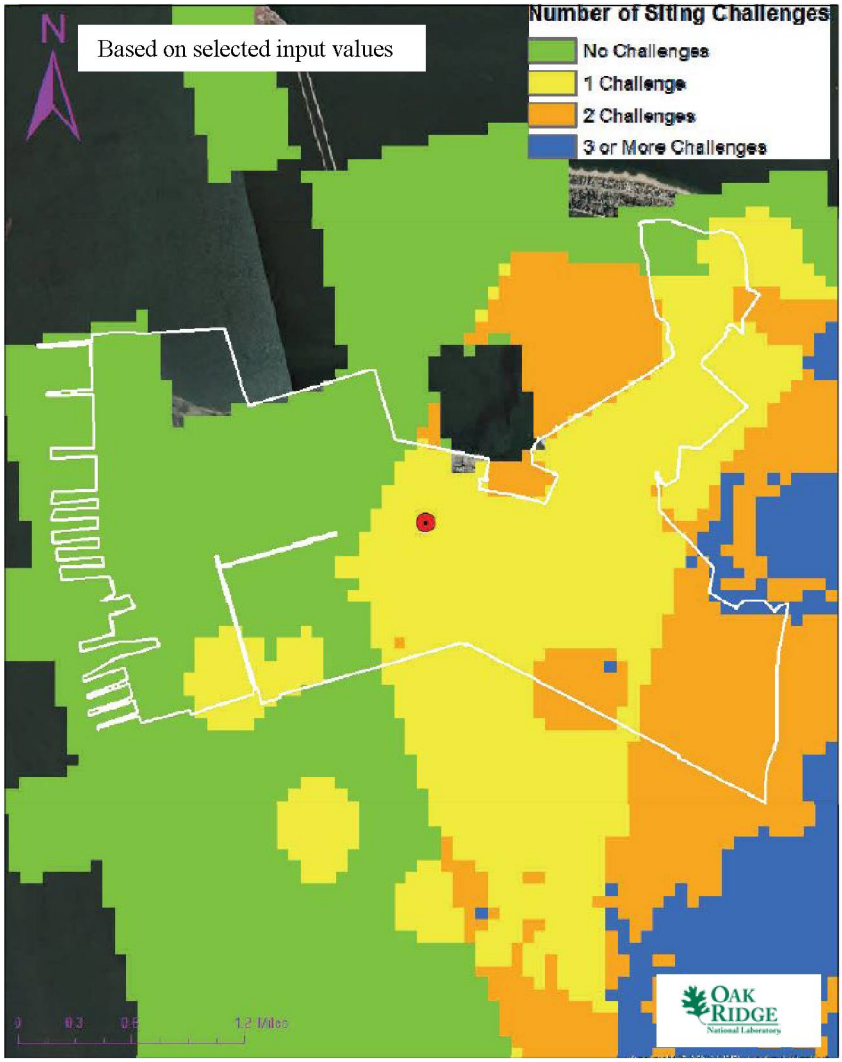

Fig. B.10. Norfolk Naval Base composite map.

B.5.3 Site Population Evaluation

The composite map above shows that the western portion of the Norfolk Naval Base site is predominantly favorable for siting an iPWR. The eastern portion of the site has an issue with stream flow, but its proximity to Chesapeake Bay and high-population areas may provide an opportunity for once-through cooling or gray water cooling.

There are some protected lands within the perimeter of the site. These are schools and unspecified federal lands. However, these lands are predominantly along the southern border. Overall, the site is heavily developed, including significant housing areas. As shown in Fig. 3, the site is on the edge of an area evaluated at 500 people per square mile within ten miles. In addition, Fig. 4 confirms that population is lighter in the immediate vicinity of the base.

B.6 YORKTOWN POWER STATION

B.6.1 Description

The Yorktown Power Station is located within Yorktown, Virginia. As shown in Fig. B.11, the site is located on the south shore of the York River near the Yorktown battlefields. The plant is approximately 13 miles southeast of Colonial Williamsburg. Rail, barge, and interstate access are all readily available to the site.

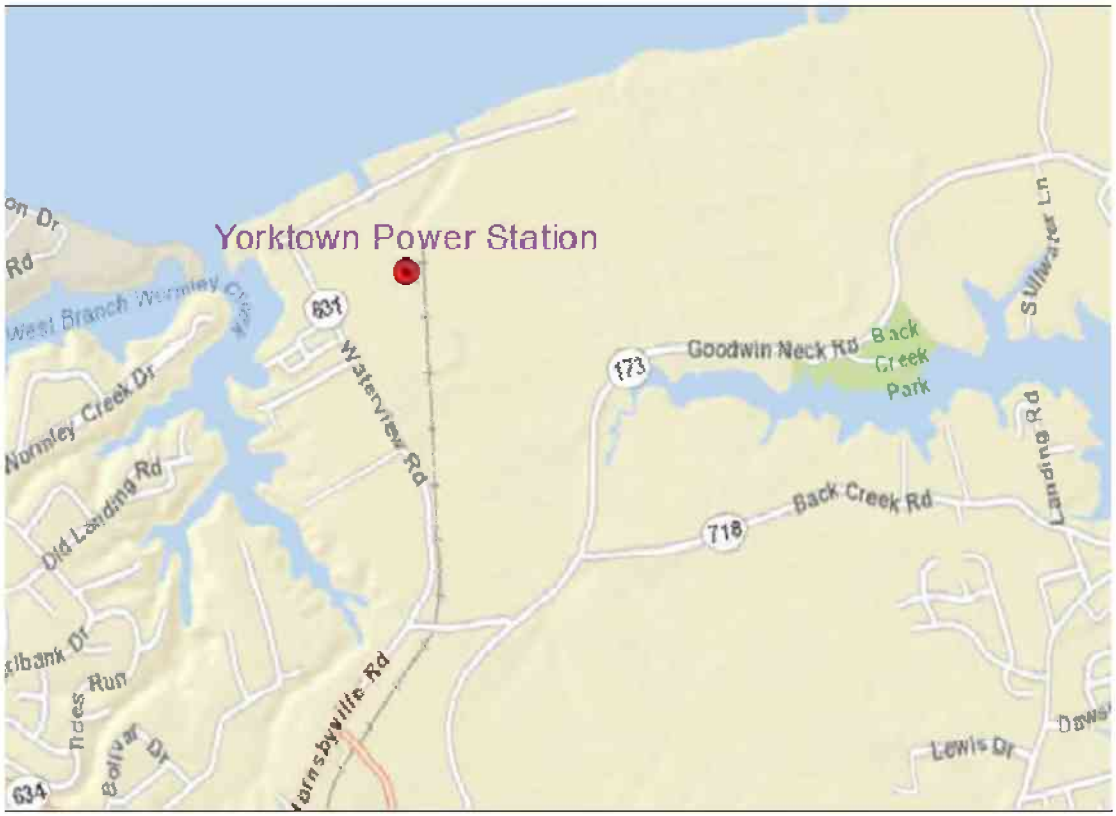

Fig. B.11. Yorktown Power Station location map.

The Yorktown Power Station is a three unit plant; two units burn coal and the third unit burns oil. The total site capacity is 1141 MW(e). The coal units are designated as Unit 1 and Unit 2, consuming 2,200 tons of coal per day. Unit 1, commissioned in 1957, is rated at 159 MW(e), and Unit 2, commissioned in 1958, is rated at 164 MW(e). Unit 3, commissioned in 1974, is rated at 818 MW(e) and consumes 20,000 barrels of oil per day. Unit 1 and Unit 2 are scheduled for closure by 2015. The units are cooled by once-through cooling from the adjacent York River. The property is immediately adjacent to a shutdown oil refinery. Numerous oil tanks dot this property, but there may be some opportunity to acquire this brownfield site to use the electricity infrastructure at the Yorktown Power Station. The power plant is estimated to sit on 250 acres.

Population immediately adjacent to the site is almost nonexistent due to the neighboring oil refinery tank farm. The permanent population within 1 mile of the plant is approximately 3,000 people[‡‡‡], yielding a population density of approximately 950 people per square mile. The permanent population within 10

[‡‡‡] All population figures in Appendix B represent gross population values and do not reflect directional population density.

miles of the plant is approximately 440,000 people, yielding a population density of about 1,400 people per square mile. The oil refinery and a water reprocessing plant are the immediate plant neighbors, with substantial green fields around this combined industrial complex. The unincorporated community of Seaford is nearby, including an elementary school.

B.6.2 Composite Map

A composite map of SMR siting challenges to the Yorktown Power Station is depicted in Fig. B.12. As shown (independent of population), the property has multiple siting issues for siting an iPWR.

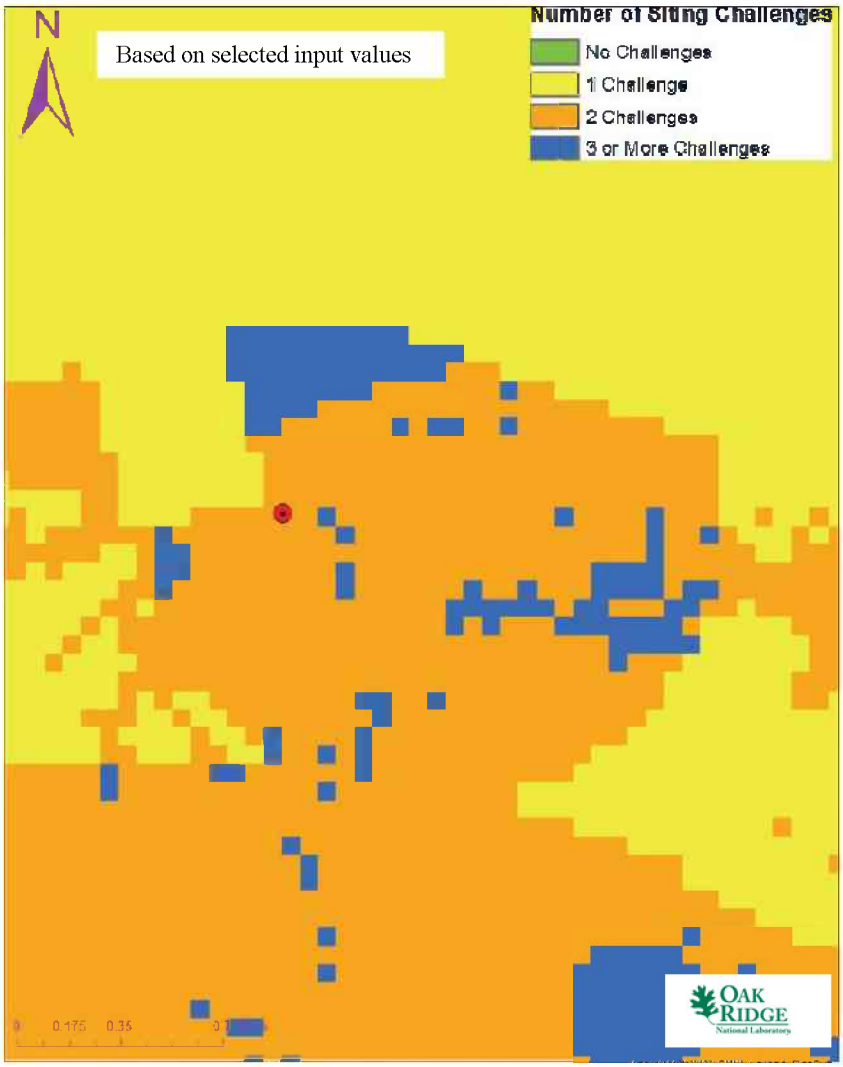

Fig. B.12. Yorktown Power Station composite map.

B.6.3 Site Population Evaluation

The composite map above shows that the Yorktown Power Station site has two significant screening issues. The first screening issue is a projected lack of freshwater makeup to support a closed cycle cooling water system for an iPWR at the site. Given the site's proximity to the York River, the Chesapeake Bay, and recycled water from a nearby reprocessing plant, there are clearly other cooling options for the site. In addition, a once-through cooling system is in operation at the site that is sized to cool at least 1141 MW(e) in generation capacity. Therefore, a lack of freshwater makeup does not appear to create a barrier

to siting an iPWR at the site. The second screening issue is due to the site's proximity to hazards. This reflects the 1 mile buffer around the adjacent oil refinery. Since the refinery is shut down, it no longer poses a hazard to siting an iPWR at the site.

The Yorktown Power Station is part of a larger industrial complex. There is little housing in very close proximity to the plant. However, the community at large is more densely populated. As shown in Fig. 3, the site is just within an area evaluated at 500 people per square mile within ten miles. However, Fig. 4 shows that population is lighter in the immediate vicinity of the power station.