9TH INTERNATIONAL CONFERENCE ON MANAGING PAVEMENT ASSETS

DETERMINING POST-EARTHQUAKE PAVEMENT REQUIREMENTS FOR CHRISTCHURCH, NEW ZEALAND

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Co-Authors:
Sean Rainsford, Technical Asset Engineer
Fulton Hogan
29 Sir William Pickering Drive, Christchurch
New Zealand

Andrew Crofts, Project Definition Team Leader
Stronger Christchurch Infrastructure Rebuild Team
1 Magdala Place, Middleton, Christchurch
New Zealand
ABSTRACT

Christchurch and surrounding areas have been devastated by a series of earthquakes ranging in magnitude from 6.3 to 7.1 since 4th September 2010. The earthquakes caused widespread damage across the city to all state owned asset infrastructure above and below ground. The local council (Christchurch City), in partnership with the national government and surrounding councils, needed to determine the extent and severity of damage to the infrastructure and then the cost to return the network to operational condition for the short term. A key part of the investigation was to determine the duration and cost to return the network to the service levels as they were prior to the earthquakes.

This paper will provide the basis of the approach taken to determine the needs of the road infrastructure, with investigations into future investment levels that would bring the network to the acceptable service levels. With the complexity of the investment decisions to be made by the network asset managers, where approximately 35% of the network was affected by extensive damage by the earthquakes, targeted use of investment was essential to ensure that the remainder of the unaffected network is not compromised through reduced investment. The inputs used for the forecast was to use readily available information, including extensive asset inventory information, forecasted demand and asset condition assessments, and measurements. Pavement performance modelling tools were used to analyse the forecasts for various investment levels. The outputs were used by key decision-makers within the council(s) and national government to ensure that the road network would be functional and at an appropriate standard to maintain economic development and social well-being.

INTRODUCTION

On the 4th September 2010, at 4:05am, the Canterbury region on the South Island of New Zealand was exposed to a major earthquake event. The earthquake had a recorded magnitude of 7.1, and was centred about 40km west from the populated city of Christchurch, to a depth of 10km. As a result of the major earthquake, and the thousands of aftershocks, widespread damage to buildings and infrastructure occurred, with no loss of life. Then on the 22nd February 2011 at 12:51pm, a second earthquake of magnitude 6.3 hit the metropolitan centre of Christchurch City (the Christchurch earthquake). The earthquake was centred about 7km from the central city of Christchurch, to a depth of 5km. The damaging impact of the second earthquake was far greater than the first earthquake to the infrastructure and buildings of Christchurch city, including loss of life. Significant liquefaction occurred in the eastern side of town, with over 400,000t of silt and sand removed.

The initial emergency response to the earthquake damage related to searching for survivors, clearing of debris, and getting roads open. The first phase of the work was the emergency response, followed by the make safe response. The Make Safe response required a quick assessment of the network, concentrating on the life-line routes, and determining functional performance of the road network. The next stage was to complete a more objective assessment of the damage to the road corridor assets. An important facet of the network
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assessment process that was undertaken within Christchurch, was to gather the information as safely as possible, prior to the make safe repair work being completed. The network damage assessment provided the basis for prioritising and determining the work locations for scoping the work required.

The Christchurch City Council (CCC) is the authority responsible for the road network infrastructure owned by the Council. The New Zealand Transport Agency is the authority responsible for the National State Highway road network within the CCC boundary. With the dual ownership responsibilities of the networks, there was a key need for collaboration between the authorities. This was controlled through the central government creating an act, called the Canterbury Earthquake Recovery Act, which provided a committed governance authority to control the recovery plan for the Canterbury region, with central government support.

As part of the long-term planning of the road network, to ensure the network was maintained and operating to the minimum standards, it was critical to understand the extent and forecasted impact of the damage to the network, balanced against the costs of returning the network to pre-earthquake levels of service. This paper provides the basis for this investigation, and process undertaken to highlight the long-term impact on the road network.

![FIGURE 1 Examples of Road Damage Caused by the Christchurch Earthquake](image)

**NEW ZEALAND GOVERNMENT SUPPORT**

Due to the scale of the damage to the buildings and infrastructure as a result from the earthquakes, the central New Zealand government created the *Canterbury Earthquake Recovery Act 2010* (with subsequent amendments in 2011 and 2012). The purpose of the Act were to provide appropriate measures to ensure that greater Christchurch and the councils and their communities respond to, and recover from, the impacts of the Canterbury earthquakes (NZ Government, 2014). As part of the act, the Canterbury Earthquake Recovery Authority (CERA) was created to administer the act. To ensure that the recovery of greater Christchurch was to be completed, the recovery was broken into different asset classes, vertical infrastructure (buildings and carparks) and horizontal infrastructure (roads, pipes and bridges). The group responsible for the recovery of the horizontal infrastructure was called the Stronger Christchurch Infrastructure Rebuild Team (SCIRT), which was an alliance of the three government organisations (CCC, New Zealand Transport Agency and CERA) and consisted of a management team with four design teams and five major contractors. The central government funded the rebuild work, through a cost sharing basis with CCC, as defined by the SCIRT damage assessment and investigations. The government cost sharing was only for the earthquake affected roads and pipes, and there was still a requirement to maintain the remainder of the network by the CCC operations team.
To determine the extent of the damage to the roads, a network level assessment was completed by all the main suppliers within the SCIRT alliance. Nearly every road within the CCC and wider area was assessed. The inspection process involved inspecting all the road corridor assets, and provide an extent of damage rank, based on minor to severe. The assets inspected were:

- Roads
- Sidewalks and Cycleways
- Kerb and Channel, including road drainage
- Retaining Walls
- Bridges
- Other ancillary assets (signs, light-poles, guardrails, etc)

The assessment method was undertaken by trained and experienced assessors, with guidance provided by SCIRT on what was expected based on the road use and classification. The survey was completed where possible, as due to the extent of liquefaction, some roads were difficult to assess. Also assessor safety was of utmost importance, as during the assessment phase, there were still aftershocks and debris falling onto the roads and sidewalks. The results of the survey are provided in TABLE 1 below.

**TABLE 1 Results of Road Network Post Earthquake Assessment**

<table>
<thead>
<tr>
<th>Damage Rating</th>
<th>Damage Description</th>
<th>Length (km)</th>
<th>Length (miles)</th>
<th>% of Network Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Damage</td>
<td>304.9</td>
<td>189.4</td>
<td>23%</td>
</tr>
<tr>
<td>1</td>
<td>Minimal</td>
<td>368.4</td>
<td>228.8</td>
<td>27%</td>
</tr>
<tr>
<td>2</td>
<td>Minor</td>
<td>334.4</td>
<td>207.7</td>
<td>25%</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>213.0</td>
<td>132.3</td>
<td>16%</td>
</tr>
<tr>
<td>4</td>
<td>Major</td>
<td>41.9</td>
<td>26.0</td>
<td>3%</td>
</tr>
<tr>
<td>5</td>
<td>Severe</td>
<td>84.2</td>
<td>52.3</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Total Network Length Assessed</strong></td>
<td></td>
<td><strong>1346.8</strong></td>
<td><strong>836.5</strong></td>
<td></td>
</tr>
</tbody>
</table>

The assessment results show that over 1,000km (640 miles) of the road network has some level of damage associated to the road corridor assets. The assessment was the first and most critical part of the data gathering process as part of the recovery phase. There was a need to ensure that the assessment was made prior to emergency repairs being completed, as the completed repairs would be temporary, and provide a false expectation of the road assets performance. The assessment was also critical in providing the framework for the basis of the cost estimate of repairing the road assets. The location and extent of the road asset assessment is provided in FIGURE 2 below.
Based on the extent of the assessed damage to the road network, further optimisation work was undertaken by SCIRT, to determine where the funding would be allocated. This optimisation process was a cross-asset and multi criteria approach, incorporating all assets (pipes, roads, sidewalks, cycleways, retaining walls, etc). This optimisation process resulted in the final list of roads that would sit within the SCIRT scope of work.

SCOPE OF WORK

The results of the optimisation process completed by SCIRT was that all roads with an assessed damage of 3 or more would be investigated, with design scopes defined for each site. This resulted in 339km (210 miles) of the network within the SCIRT scope of work. The total sealed network length that is maintained by the CCC is 1,970km (1,224 miles). The resulting network length to maintain for the CCC would be 1,631km (1,013 miles) (83%) for the duration of the rebuild phase undertaken by SCIRT. These roads would remain under the jurisdiction of CCC and require on-going maintenance as part of the current externally tendered maintenance contracts of the CCC.

The next stage of the optimisation process was to determine the scope of work to be undertaken within the 339km (210 miles). For each site identified with a damage score of 3 or more, treatment options were determined. These were categorised into 3 work types:

- Rebuild – Full pavement design of road section, complete rebuild
- Restore – Part length, not all assets, full or partial pavement design
- Repair – Small length, specific solutions, partial design requirements

After the categorisation was complete, the SCIRT design teams undertook network inspections and detailed testing to determine the final treatments to be applied (Pidwerbesky, 2014).

The SCIRT work locations to be repaired have been difficult to finalise due to political pressures, additional loading due to removal of debris by earth moving vehicles, environmental...
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decay through water ingress into the pavement and other such influences. Key to the understanding of the extent of the repair work was a communication line between the CCC operations team and the SCIRT delivery teams. This was achieved by housing a CCC staff member within the Project Scoping team of SCIRT. As part of the determination of the remainder of the network requirements, the forecasts had to be based on a fixed point of time. This was taken as the time when the analysis work was undertaken. Further work is required to fine tune the forecasts based on the changes of the SCIRT work programme within the network.

CHRISTCHURCH CITY COUNCIL REQUIREMENTS

The Christchurch City Council has an obligation to maintain the road network of Christchurch City, to provide a safe and efficient network for the community and economic benefits to the city. With the extent of damage due to the earthquake, and the subsequent scope of recovery work undertaken by the SCIRT alliance, there was still a need to maintain the remainder of the network to a functional level. As described above, the scope of the network that would remain under CCC control was 1,631km (1,013 miles). The remainder of the network to be maintained by CCC was a mixture of roads with moderate to minor earthquake damage and roads with no assessed earthquake damage. Due to the damage of the earthquake affected roads, the traffic on the unaffected roads has increased, and thereby accelerated the damage within these roads. The council wanted to determine what level of investment was required to maintain the business as usual roads at a functional level and to return the network to pre-earthquake condition.

There was also a requirement to determine the long-term impact and cost of the post SCIRT work with the remainder of the network. This would be combined with the business as usual network to get an overall impact to Christchurch City as a whole. This was a challenging task to balance the financial effect of the SCIRT work in relation to the remainder of the network. At the initial stages of the recovery phase, there was a belief within the council that the SCIRT operations would fix the assessed network to an as new level, and the long term impact would be minimal. It was discovered through the process that the level of work undertaken by SCIRT could create a potential financial legacy that had to be accounted for in the future forecasts of costs and network levels of service.

At the same time the recovery was taking place, there was a requirement to determine the long term plan for the road infrastructure assets. The process is usually done by determining the network need in relation to defined levels of service and community requirements. With the extent of the recovery and rebuild work planned on the network, the task of determining this need took on a completely unique approach. There was a need to account for the recovery and rebuild work of SCIRT within the context of the long term plan funding requirements for the entire network. This allowance was completed by utilising the treatment types proposed by SCIRT and the locations of these within the forecast. Due to the dynamic nature of the work types and locations proposed, an assumed level of work had to be used. This level of work was based on the original assessment completed combined with the more detailed scoping tasks that was being undertaken by SCIRT design teams.

The council also has an internal funding process whereby each council asset class team is required to put forward the funding requirements for the maintenance of the assets maintained. With the complexity and scale of the work required due to the earthquake damage, there was a need to ensure the basis of the funding request was realistic. This process was undertaken by the council using the deighton Total Infrastructure Management System (dTIMS) software with the Infrastructure Decision Support (IDS) Ltd pavement performance model framework.
BASIS OF FORECASTING APPROACH

The evaluation process completed to determine the long-term needs of the CCC road network was based on previous pavement performance modelling work done over the past 10 years. The key outcome of the forecasting were two-fold:
1. To determine the level of investment required to return the network to pre-earthquake condition, and
2. To determine the level of investment required to hold the network at a steady state while the recovery and rebuild work is being undertaken, without compromising the long-term performance of the road network

The base data used was updated to reflect the current nature of the network, including updated condition, asset inventory and traffic. The model also incorporated the earthquake assessments done, with the latest roughness and visual condition rating information. The road network roughness was surveyed as part of the annual condition monitoring process of the council. Although the latest survey was also of value as it provided an objective indication of the impact the earthquake damage had done to the road network.

Due to the complexity of the network, and the unknowns of the impact of the liquefied silt and sand within the pavement layers and the impact on the pavement performance, there was a need to simplify the approach of the modelling work. The approach taken was to use two key indicators to demonstrate the impacts of the various funding levels, these were:
1. Road ride quality, using the measured longitude profile through the International Roughness Index converted to an equivalent NAASRA count/km
2. Surface Condition Index, which is a composite index of various functional defects observed, including surface cracking, potholes, chip aggregate loss and bitumen flushing.

These indicators were documented within the CCC Asset Management plan and the levels of service to be provided as part of the performance framework for the transport network. The condition forecasts would be forecasted over a 20 year period, based on the different funding scenarios investigated. The condition forecasted were provided for comparative purposes between the funding levels, to assist the council with determining what level of investment would achieve the desired outcome.

ASSUMPTIONS

As previously discussed, the extent and variation of the CCC road network condition at the time after the earthquake was difficult to represent at a road section basis. Therefore assumptions had to be made to allow for this variance, these were clearly documented to ensure that the outputs would be used in the correct context. Some of the key assumptions taken into the modelling framework were:
- That the SCIRT alliance will rebuild approximately 339km (approx. 17%) of the road network over 5 years. The work will ramp up in quantity starting with 30km, up to 135km in the final year.
- SCIRT will complete 100% of the Project work by the end of 2016, i.e. there will be no back-log of work for CCC to undertake.
- The costs of secondary treatments within the SCIRT rebuild will be catered for within the CCC road maintenance budget
- The Rebuild work within the first 2 years will marginally improve roughness, the work for the last 2 years will improve road roughness in line with CCC maintenance specification target outcomes
Based on the work completed by Pidwerbesky and Waters (Pidwerbesky, 2014), the impact of the contamination of the pavements with silt and sand would not impact on the functional performance of the pavements affected.

There was also a need to remove parts of the network that would not be maintained, based on the CERA act classifying areas of the city as Red Zoned and not habitable due to unsound ground or risk of rock fall from surrounding areas.

The SCIRT work locations of work were not finalised at the time of undertaking the forecasts. Discussions were had with the Project delivery team to determine a method of prioritising where work would take place on the network. This process was based on 3 factors being:

- Change in roughness pre-earthquake to post-earthquake, where the sections with the highest change having a higher priority
- Assessed earthquake damage levels, where the higher damage level having a higher priority
- Road classification, where the key routes on the network with damage would have a higher priority

Based on these factors, work was allocated to sections of road, for the purpose of the forecasting task. This work may not actually be carried out, but the process was used to ensure that the likelihood of work taking place was in line with the methods adopted by the SCIRT delivery team.

INVESTIGATIONS UNDERTAKEN

To determine the CCC requirements as discussed previously; returning the network to pre-earthquake condition and maintain the network during the rebuild phase, seven funding scenarios were investigated, with the subsequent condition and funding profiles forecasted. As part of the financial setup within the CCC, there are different funding categories, based on the type of work undertaken within them. To ensure the forecasts would be comprehended by the CCC staff and financial group, there was a need to report the findings by these category names. The funding categories are:

- CAPEX – capital expenditure for renewal activities, such as surface resealing and pavement rehabilitation (excluding improvement work)
- OPEX – maintenance budget for operations and maintaining the network

These funding categories are reported as part of the internal funding request process. For the purpose of the forecasting, the funding categories were used with budget limits set to reflect the likely funding requests put forward as part of the review process.

The forecasted funding profiles were based on the historic pre-earthquake funding levels in place for the CCC road network. Prior to the earthquakes, CCC was investing approximately $11.5M/yr within the CAPEX budget. As a result of the earthquake, and subsequent make-safe work undertaken, the CAPEX budget was cut significantly. The council had pre-determined the level of funding that would be allocated to the CAPEX budget for the next 3 years at a funding level of $6.3M/yr or less. This level was planned to be sufficient for the remainder of the non-earthquake damaged network for the next 20 years. The predictions of the model completed highlighted the risk to the network if this investment level was maintained for the 20 year period. The CCC network operations team needed to provide a road network that would remain functional for the long term, and the forecasting work completed has provided the mechanism to communicate the long-term impact of the approved funding levels with regards to the functional performance.
There was always a need to provide a separate funding category for the earthquake make-safe repairs over a short period. The forecasting did not take this into account, as the method of where this money was used was a very reactive and unpredictable process. The earthquake make-safe repairs have been allowed for within the budgets put forward, but the impacts of the work taking place have not been taken into account with the forecasted network performance results.

The seven funding scenarios investigated were:

- **Scenario 1** – CAPEX Budget maintained at 2009-19 LTP levels ($11.5 M/Yr) until 2032
- **Scenario 2** – CAPEX Budget capped at Post EQ, 2012 levels ($6.3 M/Yr) until 2032
- **Scenario 3** – CAPEX and OPEX Budgets capped at Post EQ, 2012 levels ($6.3 M/Yr, $7.1 M/Yr) until 2032
- **Scenario 4** – CAPEX Budget required to restore network condition by 2020
- **Scenario 5** – CAPEX Budget capped at Post EQ, 2012 levels ($6.3 M/Yr) until 2015, then increased
- **Scenario 6** – CAPEX Budget capped at Post EQ, 2012 levels ($6.3 M/Yr) until 2016, then doubled
- **Scenario 7** – CAPEX and OPEX Budgets capped at Post EQ, 2012 levels ($6.3 M/Yr, $7.1 M/Yr) until 2020, to determine capital re-investment required to improve network to Pre-EQ condition

The outputs for the seven scenarios using the expenditure levels for the CAPEX budget and OPEX budget for the CCC road network are summarised in the following sections. The resulting Level of Service (LOS) impacts on the road roughness (how the road “feels” while driving), road top surface condition (how the road “looks” while driving) and OPEX budgets are provided to illustrate the consequences of the various expenditure levels.

**FINDINGS AND RECOMMENDATIONS**

For each scenario investigated, the results were combined into a network level view of the forecasted outcomes. The findings have shown that any significant reduction in the CAPEX spend in the short term directly affects the condition of the network over the long term, both in terms of the OPEX requirements and the functional performance of the roads. Based on the assumptions of the SCIRT rebuild work taking place, there was an improvement to the condition and OPEX requirements due to this, although the SCIRT work will only bring the worst cases back to a pre-earthquake standard.

The forecasts have also shown that there will be a peak of future renewals funding required which has been driven by the SCIRT work, and this is being managed carefully through the CCC Transport Asset Management Plan. The funding for the secondary work requirements on the SCIRT rebuild sites is to be accounted for within the total CCC budgets forecast. Therefore the funding for the latter years is partly allocated by the need to provide second coat seals for the rebuild sites completed.

Of the scenarios investigated, scenario 7 shows the actual cost of reducing the CAPEX and OPEX for an extended period. While the decrease in expenditure saves $40M in the short to medium term it increases the cost to complete the same work in 2021 to $60M due to increased reactive OPEX costs resulting from the pavements and surfacing assets being pushed beyond their expected renewal cycles. This would result in a total funding requirement for 2021 of $155M to return the road network back to pre-earthquake condition.
Of the 7 scenarios investigated, it is clear to see that by reducing the CAPEX budget over a longer than acceptable time period, the network will deteriorate to unacceptable levels. The total cost to CCC for each scenario is shown below:

**TABLE 2 Summary of Findings from Funding Scenarios Investigated**

<table>
<thead>
<tr>
<th>Funding Scenario</th>
<th>Funding Scenario Description ($M)</th>
<th>Average Annual CCC CAPEX Budget Levels ($M)</th>
<th>Average Annual CCC OPEX Budget Levels ($M)</th>
<th>Total CCC Annual Cost for 20 years (CAPEX and OPEX)</th>
<th>Return in Roughness Condition at Year 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>CAPEX Capped at 09-19 LTP Levels ($11.5M/Yr)</td>
<td>$11.50 M</td>
<td>$7.21 M</td>
<td>$18.71 M</td>
<td>111</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>CAPEX Capped at Post EQ 2012 Level ($6.3M/Yr)</td>
<td>$6.30 M</td>
<td>$13.06 M</td>
<td>$19.36 M</td>
<td>120</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>CAPEX and OPEX Capped at Post EQ 2012 Level ($6.3 &amp; $7.2M/Yr)</td>
<td>$6.30 M</td>
<td>$7.10 M</td>
<td>$13.40 M</td>
<td>132</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>CAPEX Required to Restore Condition by 2020</td>
<td>$12.87 M</td>
<td>$7.04 M</td>
<td>$19.91 M</td>
<td>109</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>CAPEX Capped at Post EQ 2012 Level ($6.3M/Yr) until 2015</td>
<td>$11.64 M</td>
<td>$7.69 M</td>
<td>$19.33 M</td>
<td>110</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>CAPEX Capped at Post EQ 2012 Level ($6.3M/Yr) until 2016</td>
<td>$11.21 M</td>
<td>$7.73 M</td>
<td>$18.94 M</td>
<td>111</td>
</tr>
<tr>
<td>Scenario 7</td>
<td>CAPEX and OPEX Capped at Post EQ 2012 Level until 2020</td>
<td>$18.81 M</td>
<td>$7.10 M</td>
<td>$25.91 M</td>
<td>111</td>
</tr>
</tbody>
</table>

To provide a summary of the findings with the ability to decide on the best long-term funding profiles, we have charted the information above. The axes used are based on the difference to the target outcomes desired by CCC. For the target cost (spending), we have used the CCC targets defined in the 2009 to 2019 Long Term Plan, of $11.5M CAPEX plus $7.5M OPEX for a total annual budget of $19M. For the target condition, we have used the CCC targets defined within the 2009 to 2019 Asset Management Plan, of a network average roughness target of 110 NAASRA (4.2 IRI). We have plotted the variation from the target within the charts below. For the purpose of reporting the final recommendations, we have selected 4 of the scenarios that closely matched the desired outcomes. The scenarios used were 1, 4, 5 and 6.
The chart in FIGURE 3 above compares the scenarios investigated, in terms of the total CCC funding budget combined (CAPEX and OPEX) averaged to an annualised cost over the 20 year analysis period, combined with the resulting network average roughness forecast in 20 years. The results highlight that the target roughness is achieved when funding levels are above the $6.3M CAPEX per year levels. We can also see that the total funding level is higher for the $6.3M when combined with the OPEX forecasted levels. This spending profile is the highest risk to CCC, as the increase in the funding level within the OPEX directly relates to the impact on the community through rates increases, and dissatisfaction of the road network. Therefore by keeping the funding level of $6.3M over the next 20 years is very unpalatable for the councillors and council due to the impact on the wider city community, and was discarded as an option moving forward.

The option was to now determine what funding level would be acceptable to meet the desired outcomes of:

- impact on rates,
- impact on community satisfaction, and
- financially affordable for the CCC to implement

The chart below in FIGURE 4 provides a comparison of the final 4 scenarios that provide the best outcomes in line with the CCC Asset Management Plan and Long-Term plan accepted by the council in 2009. The chart plots the 4 scenarios and the variation from the targets defined.
FIGURE 4 CCC Funding Scenario Outcome Relative to Pre-Earthquake Targets

We can see that with the increase in cost, achieving the target condition can be achieved. Based on the results of this information, it was recommended that the CAPEX budget is set to $6.3M for the short-term while the SCIRT rebuild is being undertaken, and then is increased to $12M for the next 20 years. This was accepted by the council and put forward in the long-term plan for the 2012 to 2022 period. Further work is required with on-going monitoring and investigations into the work completed by SCIRT, and the impact of the reduced investment by CCC over the same period.

REFERENCES