Investigation Report

BASEC
BRITISH APPROVALS SERVICE FOR CABLES

BASEC Client	**Electrical Safety First** Unit 331 Metal Box Factory 30 Great Guildford Street London SE1 0HS
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Items Investigated:	6 samples of Electric Cable as detailed within this Report
Investigations:	As detailed within this Report
Findings:	As detailed within this Report

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BASEC TESTING

1. Introduction

This report relates to investigative tests conducted on samples of six types of electric cable commonly used in domestic installations in the UK, as agreed with Electrical Safety First. The investigative testing was designed to simulate both short and long term immersion in various liquids that could be experienced by installed cables during periods of flooding.

This report applies only to the particular samples of cable tested and to the specific test protocols carried out and detailed within the report. Interpretation and extrapolation of these findings to different types of cable, different liquid types or conditions, or to greater depths of water is not recommended without further work.

The investigative testing was conducted without energising the cables, except for conducting specific cable condition tests as detailed in the report. The possible effects of impingement of water on energised cable installations have not been investigated. Attention is drawn to the potential safety hazards of electricity and water in combination.

2. Cable Types and Samples

The cable types used in the investigative testing were chosen to reflect a range of types and sizes of building wiring commonly used in domestic installations in the UK. The samples used were not tested for conformity to the relevant cable specifications before being subjected to the investigative testing. All the samples carried a relevant approval marking (e.g., BASEC) on the cable, and were therefore presumed to conform to the relevant cable specifications, as detailed below. Nothing emerged during the testing or examination to suggest that any of the samples used were not in conformity with the relevant specifications.

The cable samples were chosen at random from readily available stock without reference to the identity of, or consultation with, their manufacturer, and hence it would not be appropriate in this report to identify the manufacturers of the particular cables used. There are sometimes minor differences between cables from different manufacturers arising from their use of differently sourced precursor materials and in their manufacturing processes, but the samples in question were all declared to conform to the relevant cable specifications. A comprehensive review of the performance of cable types from a range of manufacturers is beyond the scope of this work and report.

The types of electric cable used in the investigative testing were as follows:

A Single core PVC building wire, **solid** conductor.
1 X 1.5mm² single core class 1 solid conductor with blue insulation.
Harmonised code designation: H07V-U, UK cable code: 6491X.
Specification: BS EN 50525-2-31:2011, clause 4.1, rated 450/750V.

B Single core PVC building wire, **solid** conductor.
1 X 2.5mm² single core class 1 conductor with brown insulation.
Harmonised code designation: H07V-U, UK cable code: 6491X.
Specification: BS EN 50525-2-31:2011, clause 4.1, rated 450/750V.

C Single core PVC building wire, **stranded** conductor.
1 X 4.0mm² single core class 2 conductor with green-and-yellow insulation.
Harmonised code designation: H07V-R, UK cable code: 6491X.
Specification: BS EN 50525-2-31:2011, clause 4.1, rated 450/750V.

D Twin and earth PVC cable, **solid** conductors, with solid CPC.
2 x 2.5mm2 twin & earth class 1 conductors with grey sheath.
UK cable code: 6242Y.
Specification: BS 6004:2012, table 4, rated 300/500V.

E Twin and earth PVC cable, **stranded** conductors, with solid CPC.
2 x 2.5mm2 twin & earth class 2 conductors with grey sheath.
UK cable code: 6242Y.
Specification: BS 6004:2012, table 5, rated 300/500V.

F Twin and earth LSHF cable, **solid** conductors, with solid CPC.
2 x 2.5mm2 twin & earth class 1 conductors with white sheath.
UK cable code: 6242B.
Specification: BS 7211:2012, table 5, rated 300/500V.

Notes:

Types A to E were made of PVC materials; type F was made of low smoke halogen free (LSHF) material.

Types A, B, D and F were of solid conductor construction; types C and E were of stranded construction.

3. Test Protocols

The following test protocols were employed to investigate the penetration of water into immersed open ends of cables, and to investigate the electrical performance of the cables after or during immersion, and to ascertain any degradation in the performance of the sheathing material.

Protocol 1 - Wicking:

Samples of cable of types A to F, each 2m long, were suspended vertically in liquid in three separate tanks containing (a) clean, (b) salty and (c) silty water, with a length of 20cm immersed below the surface. After an immersion period of one week, each sample was removed from the relevant test tank, cut open every 2cm starting at the immersed end and visually inspected for the presence of water inside the cable, between the conductor and insulation and (where appropriate) between the insulation / CPC and the sheath.

Protocol 2 - Penetration:

Samples of cable of types A to F, each 5m long, were suspended horizontally in liquid in three separate tanks containing (a) clean, (b) salty and (c) silty water. One end of each sample was kept 1m clear of the liquid, with the remainder coiled at an immersion depth of 1m. After an immersion period of 1 week, each sample was removed from the relevant test tank, cut open every 10cm and visually inspected for the presence of water inside the cable, between the conductor and insulation and (where appropriate) between the insulation / CPC and the sheath.

Protocol 3 – Insulation Resistance on Drying:

Samples of cable of types D to F, each 2m long with 1m immersed, were suspended vertically in liquid in three separate tanks containing (A) clean, (B) salty and (C) silty water. After an immersion period of 24 hours, each sample was removed from the relevant tank and allowed to dry in a vertical orientation. The insulation resistance of each sample was measured between the phase and neutral conductors bonded together and the circuit protective conductor, using a 500Vdc insulation resistance tester. This test was repeated at times 15min, 30min, 45min, 4hrs, 24hrs, 48hrs and 1 week after removal from the liquid.

Protocol 4 – Medium Term Immersion Insulation Resistance:

Samples of cable of types E and F, each 5m long, were suspended in liquid in three separate tanks containing (A) clean, (B) salty and (C) silty water. The samples were coiled and suspended at a depth of 1m, with both ends kept clear of the liquid surface. During the period of immersion the insulation resistance of each sample was measured between the conductors and circuit protective conductor bonded together and the immersion liquid, using a 500Vdc insulation resistance tester. The samples were also subjected to high voltage withstand test at 2000Vac between the conductors and the immersion liquid. The measurements were repeated at times 1 week, 2 weeks, 1 month and 3 months after immersion.

Protocol 5 – Model Flood, Insulation Resistance on Drying:

Samples of cable of types D, E and F, each 5m long, with both ends stripped for normal accessory termination (100mm of insulation and 12mm copper visible), were suspended in liquid in three separate tanks containing (A) clean, (B) salty and (C) silty water, a total of nine samples. The samples were coiled and suspended at a depth of 1m, with both ends immersed at the same depth. The samples were immersed for a period of one week, and then removed and left to dry naturally at ambient temperature. The exposed and stripped ends were dried manually with tissue before the first post-immersion test. During the drying period the insulation resistance of each sample was measured between each conductor and the circuit protective conductor, using a 500Vdc insulation resistance tester. The measurements were repeated daily and then weekly for several weeks after removal from the tanks. On completion of the measurements, the samples were slit and internally examined.

Protocol 5 work was completed as a separate work item following the completion of work on Protocols 1 to 4.

Immersion liquids:

(a) Clean water was potable tap water, taken from local Milton Keynes mains water, without any filtering, softening, deionisation or other treatment. There was no agitation in the tank containing this liquid.

(b) Salty water was potable tap water (as above) with sufficient NaCl added to give an approximate salinity of 3.5%. This reflects the typical salinity of seawater. There was no agitation in the tank containing this liquid.

(c) Silty water was potable tap water (as above) with plastering sand and top soil added (approximately 3kg of each in 300l of water). The sand and soil were kept in suspension by agitating the water with a recirculating pump. The pump was switched on for 4hrs and off for 2hrs throughout the duration of immersion of samples.

Environmental conditions:

Opaque black plastic tanks each containing approximately 300l of water were kept for the duration of the testing in the BASEC laboratory warehouse, adjacent to the insulation resistance / voltage test area. The temperature in the warehouse area was logged and was recorded during the testing. The average air temperature during the period of initial testing (October to December 2014) was 18.7°C, with a maximum of 24.9°C and a minimum of 12.6°C, with diurnal variation. The average air temperature during the period of follow-up testing for protocol 5 (August to November 2015) was 23°C, with a maximum of 27°C and a minimum of 18°C, with diurnal variation. The average relative humidity in the laboratory area during this period was 48%RH, with a maximum of 58%RH and a minimum of 37%RH. Atmospheric pressure varied between 985mBar and 1010mBar, with an average of 998mBar.

Photographs of the arrangements and cable conditions after test are included in Annex B.

4. Results of Tests

The detailed results of the individual tests and examinations for each of the protocols carried out are detailed in the Annex.

The following are tabulated summaries of the results.

Protocol 1 - Wicking: 2m sample vertical dip, 20cm immersed for 1 week at room temperature Results show water penetration in cm						
	A 6491X 1 x 1.5mm2 Solid	B 6491X 1 x 2.5mm2 Solid	C 6491X 1 x 4.0mm2 Stranded	D 6242Y 2 x 2.5mm2 Solid	E 6242Y 2 x 2.5mm2 Stranded	F 6242B 2 x 2.5mm2 Solid
Clean water	0	0	0	8	32	2
Salty water	0	0	2	2	30	2
Silty water	0	0	0	10	8	0

Protocol 2 - Penetration: 4m coil of sample immersed in 1m water with 1m of sample out of water for 1 week at room temperature Results show water penetration in cm						
	A 6491X 1 x 1.5mm2 Solid	B 6491X 1 x 2.5mm2 Solid	C 6491X 1 x 4.0mm2 Stranded	D 6242Y 2 x 2.5mm2 Solid	E 6242Y 2 x 2.5mm2 Stranded	F 6242B 2 x 2.5mm2 Solid
Clean water	0	0	500	10	300	0
Salty water	0	0	500	410	190	0
Silty water	0	0	500	340	340	0

Protocol 3 – Insulation Resistance on Drying: 2m sample vertical dip, 1m immersed for 24hrs at room temperature. Times are after removal from solution. Results show insulation resistance.						
	A 6491X 1 x 1.5mm2 Solid	B 6491X 1 x 2.5mm2 Solid	C 6491X 1 x 4.0mm2 Stranded	D 6242Y 2 x 2.5mm2 Solid	E 6242Y 2 x 2.5mm2 Stranded	F 6242B 2 x 2.5mm2 Solid
Clean water						
Before test	-	-	-	70GΩ	80GΩ	>100GΩ
15 min.	-	-	-	35GΩ	60GΩ	>100GΩ
30 min.	-	-	-	35GΩ	60GΩ	>100GΩ
45 min.	-	-	-	35GΩ	60GΩ	>100GΩ
4hr	-	-	-	20GΩ	50GΩ	>100GΩ
24hr	-	-	-	35GΩ	50GΩ	>100GΩ
48hr	-	-	-	30GΩ	35GΩ	>100GΩ
1 week	-	-	-	30GΩ	50GΩ	>100GΩ
Salty water						
Before test	-	-	-	40GΩ	90GΩ	>100GΩ
15 min.	-	-	-	28GΩ	125MΩ	1.06GΩ
30 min.	-	-	-	29GΩ	256MΩ	18.5GΩ
45 min.	-	-	-	30GΩ	1.97GΩ	>100GΩ
4hr	-	-	-	35GΩ	50GΩ	>100GΩ
24hr	-	-	-	35GΩ	70GΩ	>100GΩ
48hr	-	-	-	30GΩ	60GΩ	>100GΩ
1 week	-	-	-	35GΩ	60GΩ	>100GΩ
Silty water						
Before test	-	-	-	50GΩ	100GΩ	>100GΩ
15 min.	-	-	-	35GΩ	19.5GΩ	45GΩ
30 min.	-	-	-	30GΩ	25GΩ	>100GΩ
45 min.	-	-	-	30GΩ	35GΩ	>100GΩ
4hr	-	-	-	35GΩ	60GΩ	>100GΩ
24hr	-	-	-	40GΩ	70GΩ	>100GΩ
48hr	-	-	-	40GΩ	60GΩ	>100GΩ
1 week	-	-	-	30GΩ	60GΩ	>100GΩ

Protocol 4 – Medium Term Immersion Insulation Resistance: 5m samples immersed to 1m with ends clear of solution, for 3 months, at room temperature. Times are from the start of immersion. Results show insulation resistance and result of HV test						
	A 6491X 1 x 1.5mm2 Solid	B 6491X 1 x 2.5mm2 Solid	C 6491X 1 x 4.0mm2 Stranded	D 6242Y 2 x 2.5mm2 Solid	E 6242Y 2 x 2.5mm2 Stranded	F 6242B 2 x 2.5mm2 Solid
Clean water						
Before, HV	-	-	-	-	Pass	Pass
Before, IR					12.6GΩ	>100GΩ
1 week, HV	-	-	-	-	Pass	Pass
1 week IR	-	-	-	-	9.96GΩ	>100GΩ
2 weeks, HV	-	-	-	-	Pass	Pass
2 weeks IR	-	-	-	-	4.7GΩ	>100GΩ
1 month, HV	-	-	-	-	Pass	Pass
1 month IR	-	-	-	-	4.3GΩ	>100GΩ
3 month, HV	-	-	-	-	Pass	Pass
3 month, IR	-	-	-	-	4.1GΩ	>100GΩ
Salty water						
Before, HV	-	-	-	-	Pass	Pass
Before, IR					7.1GΩ	>100GΩ
1 week, HV	-	-	-	-	Pass	Pass
1 week IR	-	-	-	-	2.97GΩ	>100GΩ
2 weeks, HV	-	-	-	-	Pass	Pass
2 weeks IR	-	-	-	-	2.43GΩ	>100GΩ
1 month, HV	-	-	-	-	Pass	Pass
1 month IR	-	-	-	-	1.43GΩ	>100GΩ
3 month, HV	-	-	-	-	Pass	Pass
3 month, IR	-	-	-	-	1.3GΩ	>100GΩ
Silty water						
Before, HV	-	-	-	-	Pass	Pass
Before, IR					4.6GΩ	>100GΩ
1 week, HV	-	-	-	-	Pass	Pass
1 week IR	-	-	-	-	1.95GΩ	>100GΩ
2 weeks, HV	-	-	-	-	Pass	Pass
2 weeks IR	-	-	-	-	1.43GΩ	>100GΩ
1 month, HV	-	-	-	-	Pass	Pass
1 month IR	-	-	-	-	1.29GΩ	>100GΩ
3 month, HV	-	-	-	-	Pass	Pass
3 month, IR	-	-	-	-	1.11GΩ	>100GΩ

Protocol 5 – Model Flood, Insulation Resistance on Drying

Protocol 5 – Model Flood, Insulation Resistance on Drying:
5m samples immersed to 1m with ends immersed at depth, for 1 week, at room temperature. Times are from the start of drying. Results show insulation resistance brown-CPC and blue-CPC.

	D 6242Y 2 x 2.5mm2 Solid L - CPC	D 6242Y 2 x 2.5mm2 Solid N - CPC	E 6242Y 2 x 2.5mm2 Stranded L - CPC	E 6242Y 2 x 2.5mm2 Stranded N - CPC	F 6242B 2 x 2.5mm2 Solid L - CPC	F 6242B 2 x 2.5mm2 Solid N - CPC
Clean water						
Pre-test	6.2GΩ	8.6GΩ	60GΩ	60GΩ	>100GΩ	>100GΩ
Post-test	1.71GΩ	1.93GΩ	26GΩ	30GΩ	>100GΩ	>100GΩ
24 hrs	928MΩ	1.10GΩ	19GΩ	22GΩ	>100GΩ	>100GΩ
48 hrs	829MΩ	969MΩ	17.5GΩ	20GΩ	>100GΩ	>100GΩ
72 hrs	871MΩ	1.17GΩ	18GΩ	21GΩ	>100GΩ	>100GΩ
1 week	1.04GΩ	1.16GΩ	21GΩ	23GΩ	>100GΩ	>100GΩ
2 weeks	1.18GΩ	1.27GΩ	24GΩ	26GΩ	>100GΩ	>100GΩ
3 weeks	1.30GΩ	1.37GΩ	28GΩ	29GΩ	>100GΩ	>100GΩ
1 month	1.18GΩ	1.25GΩ	27GΩ	30GΩ	>100GΩ	>100GΩ
2 months	361MΩ	457MΩ	40GΩ	40GΩ	>100GΩ	>100GΩ
3 months	249MΩ	351MΩ	60GΩ	70GΩ	>100GΩ	>100GΩ
Salty water						
Pre-test	6.7GΩ	8.4GΩ	60GΩ	70GΩ	>100GΩ	>100GΩ
Post-test	1.10GΩ	629MΩ	50.2MΩ	316MΩ	76GΩ	2.86GΩ
24 hrs	854MΩ	53.8MΩ	110MΩ	366MΩ	>100GΩ	>100GΩ
48 hrs	736MΩ	149MΩ	204MΩ	508MΩ	>100GΩ	>100GΩ
72 hrs	781MΩ	158MΩ	744MΩ	439MΩ	>100GΩ	>100GΩ
1 week	911MΩ	727MΩ	1.47GΩ	12.5GΩ	>100GΩ	>100GΩ
2 weeks	1.03GΩ	998MΩ	4.9GΩ	22GΩ	>100GΩ	>100GΩ
3 weeks	1.08GΩ	1.10GΩ	1.61GΩ	23GΩ	>100GΩ	>100GΩ
1 month	939MΩ	1.01GΩ	789MΩ	26GΩ	>100GΩ	>100GΩ
2 months	274MΩ	339MΩ	355MΩ	35GΩ	>100GΩ	>100GΩ
3 months	206MΩ	261MΩ	1.20GΩ	50GΩ	>100GΩ	>100GΩ
Silty water						
Pre-test	6.6GΩ	8.7GΩ	70GΩ	70GΩ	>100GΩ	>100GΩ
Post-test	2.39GΩ	2.61GΩ	35GΩ	22.5GΩ	>100GΩ	>100GΩ
24 hrs	1.01GΩ	1.13GΩ	25GΩ	5.36GΩ	>100GΩ	>100GΩ
48 hrs	841MΩ	934MΩ	22GΩ	4.96GΩ	>100GΩ	>100GΩ
72 hrs	874MΩ	962MΩ	23GΩ	15GΩ	>100GΩ	>100GΩ
1 week	956MΩ	1.04GΩ	22GΩ	19.5GΩ	>100GΩ	>100GΩ
2 weeks	1.07GΩ	1.15GΩ	24GΩ	24GΩ	>100GΩ	>100GΩ
3 weeks	1.12GΩ	1.19GΩ	27GΩ	25GΩ	>100GΩ	>100GΩ
1 month	1.02GΩ	1.09GΩ	27GΩ	24GΩ	>100GΩ	>100GΩ
2 months	398MΩ	402MΩ	35GΩ	30GΩ	>100GΩ	>100GΩ
3 months	170MΩ	222MΩ	50GΩ	50GΩ	>100GΩ	>100GΩ

Note: the differences in baseline IR values between cables D and E are attributable to different polymer blends used by different manufacturers (these cables were from two different manufacturers).

5. Findings and Discussion

Findings:

Protocol 1 - Wicking:

Wicking of water up the cables above the surface level was found to occur significantly only with smaller stranded conductors. Penetration into other cables was minimal.

Protocol 2 - Penetration:

Penetration of submerged cable ends was not observed for solid single core cable or LSHF twin and earth, but did occur extensively with the stranded conductor cables and with solid PVC twin and earth.

Protocol 3 – Insulation Resistance on Drying:

Insulation resistance of immersed and removed sheathed cables was not affected with solid PVC twin and earth but short term reductions were seen with stranded PVC and solid LSHF cables. All readings recovered to high levels within one hour of removal from water. At no time did the insulation resistance readings (for the short length of cable measured) fall near to Wiring Regulations concern levels.

Protocol 4 – Medium Term Immersion Insulation Resistance:

No voltage test breakdowns were observed during testing. Insulation resistances were seen to fall steadily over time for the PVC twin and earth, but remained higher than the measurement limit for the LSHF cable at all times. At no time did the insulation resistance readings (for the short length of cable measured) fall near to Wiring Regulations concern levels. After three months in liquid the cables in salty and silty water were somewhat discoloured, but despite this the electrical performance remained satisfactory.

Protocol 5 – Model Flood, Insulation Resistance on Drying

There was no observable different in the condition of the cables after immersion from the Protocol 4 case. The cables all tested acceptably on each occasion where they were tested. There was a difference in baseline insulation resistance between the D and E samples attributable to differences in polymer and manufacturer.

The insulation resistance readings were taken between each conductor and the uninsulated CPC, and hence was probing the electrical properties of the insulation material in the region where it is in close proximity to the CPC.

The low smoke halogen free type (6242B) (F) was observed immediately post-immersion in the salty water to show reduced insulation resistance for both cores, but these readings recovered within 24 hours, to 'off scale'. All other readings for this cable from the other two immersion liquids, and at all other times for the salty water, were 'off scale'. This cable therefore demonstrated considerable resilience to the model flood, with rapid recovery. On completion of the readings the cable was slit and examined internally. The CPC was discoloured (blackish deposit) where in contact with salty / silty water – water appeared to have penetrated along the CPC within the sheath. There was no penetration by water along the conductor in the two cores, between the copper and the XLPE insulation.

For the two PVC types (6242Y) (D and E) the insulation resistance readings dropped after removal from the immersion liquids, and then continued to drop for a few days afterwards, only then beginning to slowly recover. The salty water produced the largest decreases in insulation resistance; clean and silty water resulted in similar behaviours.

By the end of the measurement period sample D had not fully recovered completely to its original level of insulation resistance, suggesting that there could be a longer-term effect on the specific PVC insulation material used, not seen with the LSHF material of sample F or the PVC material of sample E. The final readings for sample D appeared to be continuing to fall even at the end of the measurement period. This suggests that the immersion could have introduced a long-term change in the properties of the PVC insulation of this particular manufacturer's cable.

The other sample of PVC cable (E) had in most cases recovered to near pre-test insulation resistance readings by one month, and these continued to improve. Only the salty water case differed for this cable. This suggests that the PVC insulation used by this manufacturer was more resilient to immersion and that once dried out it returned to its pre-test state.

It should be noted that the more variable PVC cable (D) had lower initial insulation resistance values (6GΩ to 9GΩ) than the more resilient one (E) (60GΩ to 70GΩ).

Once testing had been completed the cables were slit for internal examination. Both cables showed full penetration of water along the CPC (as evidenced by discolouration of the CPC). The solid conductor sample (D) showed penetration of around 300mm. The stranded conductor sample (E) showed extensive penetration within the core, as would be expected from its more open conductor construction.

At all stages the measured insulation resistances of all cables from all immersion liquids were acceptable from a Wiring Regulations point of view, even at their lowest points. However, the measured length was only 5m and no accessories were fitted.

Discussion:

Stranded conductor cables appear significantly more prone to liquid penetration than solid conductor cables. This can be rationalised because of the air spaces between strands of the conductor in the case of a stranded conductor. There appears to be lower potential for penetration up solid conductor cables. It might be suggested that in flood-prone installations stranded conductors are avoided.

Insulation resistance values (for the short lengths of cable measured) did not fall close to Wiring Regulations concern levels. This suggests that there was insignificant degradation of the materials in the liquids investigated, and that following suitable drying out and safety checks the cables could be re-energised with little observable difference in performance. However, some long-term differences in baseline insulation resistance could be seen for one of the PVC cables.

Salty water appeared to be more problematic to recover from, with lower insulation resistance values seen and variability continuing over time.

Insulation resistance values were much higher, and recovery periods after flooding much shorter, for LSHF cables than for PVC.

A combination of solid conductors and LSHF cables (6242B) appeared to have the best performance in these tests.

Differences were apparent between the PVC insulation materials used by the two different manufacturers. One manufacturer's cable recovered from clean or silty water immersion almost completely to pre-test levels, even though its conductors were stranded, whereas another manufacturer's cable continued to exhibit much lower values and on-going variability. Currently there is no standardised test applied to these cables during manufacture or for certification purposes which would identify such material behaviour.

It should be noted that the measurements were conducted over a relatively short period and no assessment of potential changes in the longevity (normal usage lifetime of 20+ years) of the cables was attempted.

No issues emerged from this work that might suggest a referral to the relevant British Standards committee for these cables.

Possible Recommendations for Consideration / Verification:

For a new installation / rewire in a flood-prone area:

- Consider using LSHF type twin and earth cables rather than PVC cables.
- Use solid conductor rather than stranded.
- Consider the merits of not using a cable with an uninsulated CPC.
- Where PVC cables are used, use a cable with high initial insulation resistance.

In case of a flood:

- Test and monitor the insulation resistance of flooded cables during the drying process, once isolated, comparing them where possible to tests on non-flooded cables (for example an isolated length of identical cable in an upstairs circuit).
- LSHF cables (solid conductor) may dry out and be re-usable within a few days.
- The drying out of PVC cables may take longer and may not recover fully.
- If the insulation resistance values continue to be significantly lower or are not improving after 1 week / 1 month, then consider replacement.

6. Suggestions for Possible Further Work

Investigation of the effects of short circuit on energised cables during inundation.

Survey of different manufacturers' cables to determine if there are differences in performance as regards recovery from flooding. This should be applied to both PVC and LSHF types.

Annex A – Details of Tests and Examinations

Cable Samples of Type A

Protocol 1:

Clean water: No water penetration noted

Salty water: No water penetration noted

Silty water: No water penetration noted

Protocol 2:

Clean water: No water penetration noted

Salty water: No water penetration noted

Silty water: No water penetration noted

Cable Samples of Type B

Protocol 1:

Clean water: No water penetration noted

Salty water: No water penetration noted

Silty water: No water penetration noted

Protocol 2:

Clean water: No water penetration noted

Salty water: No water penetration noted

Silty water: No water penetration noted

Cable Samples of Type C

Protocol 1:

Clean water: No water penetration noted

Salty water: Water penetration noted at 2cm from end but not beyond

Silty water: No water penetration noted

Protocol 2:

Clean water: Water penetration noted up to and including 500cm from end

Salty water: Water penetration noted up to and including 500cm from end

Silty water: Water penetration noted up to and including 500cm from end

Cable Samples of Type D

Protocol 1:

Clean water: Water penetration noted up to and including 8cm from end

Salty water: Water penetration noted at 2cm from end but not beyond

Silty water: Water penetration noted up to and including 10cm from end

Protocol 2:

Clean water: Water penetration noted up to and including 10cm from end

Salty water: Water penetration noted up to and including 410cm from end

Silty water: Water penetration noted up to and including 340cm from end

Protocol 3:

	Start	15min	30min	45min	4hrs	24hrs	48hrs	1 week
Clean water:	70GΩ	35GΩ	35GΩ	35GΩ	20GΩ	35GΩ	30GΩ	30GΩ
Salty water:	40GΩ	28GΩ	29GΩ	30GΩ	35GΩ	35GΩ	30GΩ	35GΩ
Silty water:	50GΩ	35GΩ	30GΩ	30GΩ	35GΩ	40GΩ	40GΩ	30GΩ

Protocol 5:

	Pre-test	Post-test	24 hrs	48 hrs	72 hrs	1 week	2 weeks	3 weeks
Clean water:	6.2GΩ	1.71GΩ	928MΩ	829MΩ	871MΩ	1.04GΩ	1.18GΩ	1.30GΩ
	8.6GΩ	1.93GΩ	1.10GΩ	969MΩ	1.17GΩ	1.16GΩ	1.27GΩ	1.37GΩ
Salty water:	6.7GΩ	1.10GΩ	854MΩ	736MΩ	781MΩ	911MΩ	1.03GΩ	1.08GΩ
	8.4GΩ	629MΩ	54MΩ	149MΩ	158MΩ	727MΩ	998MΩ	1.10GΩ
Silty water:	6.6GΩ	2.39GΩ	1.01GΩ	841MΩ	874MΩ	956MΩ	1.07GΩ	1.12GΩ
	8.7GΩ	2.61GΩ	1.13GΩ	934MΩ	962MΩ	1.04GΩ	1.15GΩ	1.19GΩ

	1 month	2 months	3 months
Clean water:	1.18GΩ	361MΩ	249MΩ
	1.25GΩ	457MΩ	351MΩ
Salty water:	939MΩ	247MΩ	206MΩ
	1.01GΩ	339MΩ	261MΩ
Silty water:	1.02GΩ	398MΩ	170MΩ
	1.09GΩ	402MΩ	222MΩ

Cable Samples of Type E

Protocol 1:

Clean water: Water penetration noted up to and including 32cm from end

Salty water: Water penetration noted up to and including 30cm from end

Silty water: Water penetration noted up to and including 8cm from end

Protocol 2:

Clean water: Water penetration noted up to and including 300cm from end

Salty water: Water penetration noted up to and including 190cm from end

Silty water: Water penetration noted up to and including 340cm from end

Protocol 3:

	Start	15min	30min	45min	4hrs	24hrs	48hrs	1 week
Clean water:	80GΩ	60GΩ	60GΩ	60GΩ	50GΩ	50GΩ	35GΩ	50GΩ
Salty water:	90GΩ	125MΩ	256MΩ	1.97GΩ	50GΩ	70GΩ	60GΩ	60GΩ
Silty water:	100GΩ	19.5GΩ	25GΩ	35GΩ	60GΩ	70GΩ	60GΩ	60GΩ

Protocol 4:

	Start		1 week		2 weeks		1 month		3 months	
	IR	HV	IR	HV	IR	HV	IR	HV	IR	HV
Clean water:	12.60GΩ	Pass	9.96GΩ	Pass	4.70GΩ	Pass	4.30GΩ	Pass	4.10GΩ	Pass
Salty water:	7.10GΩ	Pass	2.97GΩ	Pass	2.43GΩ	Pass	1.43GΩ	Pass	1.30GΩ	Pass
Silty water:	4.60GΩ	Pass	1.95GΩ	Pass	1.43GΩ	Pass	1.29GΩ	Pass	1.11GΩ	Pass

Protocol 5:

	Pre-test	Post-test	24 hrs	48 hrs	72 hrs	1 week	2 weeks	3 weeks
Clean water:	60GΩ	26GΩ	19GΩ	17.5GΩ	18GΩ	21GΩ	24GΩ	28GΩ
	60GΩ	30GΩ	22GΩ	20GΩ	21GΩ	23GΩ	26GΩ	29GΩ
Salty water:	60GΩ	50.2MΩ	110MΩ	204MΩ	744MΩ	1.47GΩ	4.9GΩ	1.61GΩ
	70GΩ	316MΩ	366MΩ	508MΩ	439MΩ	12.5GΩ	22GΩ	23GΩ
Silty water:	70GΩ	35GΩ	25GΩ	22GΩ	23GΩ	22GΩ	24GΩ	27GΩ
	70GΩ	22.5GΩ	5.36GΩ	4.96GΩ	15GΩ	19.5GΩ	24GΩ	25GΩ

	1 month	2 months	3 months
Clean water:	27GΩ	40GΩ	60GΩ
	30GΩ	40GΩ	70GΩ
Salty water:	789MΩ	355MΩ	1.20GΩ
	26GΩ	35GΩ	50GΩ
Silty water:	27GΩ	35GΩ	50GΩ
	24GΩ	30GΩ	50GΩ

Cable Samples of Type F: 6242B 2 x 2.5sqmm Solid conductor

Protocol 1:

Clean water: Water penetration noted at 2cm from end but not beyond

Salty water: Water penetration noted at 2cm from end but not beyond

Silty water: No water penetration noted

Protocol 2:

Clean water: No water penetration noted

Salty water: No water penetration noted

Silty water: No water penetration noted

Protocol 3:

	Start	15min	30min	45min	4hrs	24hrs	48hrs	1 week
Clean water:	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ
Salty water:	> 100GΩ	1.06GΩ	18.5GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ
Silty water:	> 100GΩ	45GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ	> 100GΩ

Protocol 4:

	Start		1 week		2 weeks		1 month		3 months	
	IR	HV	IR	HV	IR	HV	IR	HV	IR	HV
Clean water:	>100GΩ	Pass	>100GΩ	Pass	>100GΩ	Pass	>100GΩ	Pass	>100GΩ	Pass
Salty water:	>100GΩ	Pass	>100GΩ	Pass	>100GΩ	Pass	>100GΩ	Pass	> 100GΩ	Pass
Silty water:	>100GΩ	Pass	>100GΩ	Pass	>100GΩ	Pass	>100GΩ	Pass	> 100GΩ	Pass

Protocol 5:

	Pre-test	Post-test	24 hrs	48 hrs	72 hrs	1 week	2 weeks	3 weeks
Clean water:	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ
	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ
Salty water:	>100GΩ	76GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ
	>100GΩ	2.86GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ
Silty water:	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ
	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ	>100GΩ

	1 month	2 months	3 months
Clean water:	>100GΩ	>100GΩ	>100GΩ
	>100GΩ	>100GΩ	>100GΩ
Salty water:	>100GΩ	>100GΩ	>100GΩ
	>100GΩ	>100GΩ	>100GΩ
Silty water:	>100GΩ	>100GΩ	>100GΩ
	>100GΩ	>100GΩ	>100GΩ

Annex B – Photographs

Figure 1: Arrangement of tanks and suspension of cables.

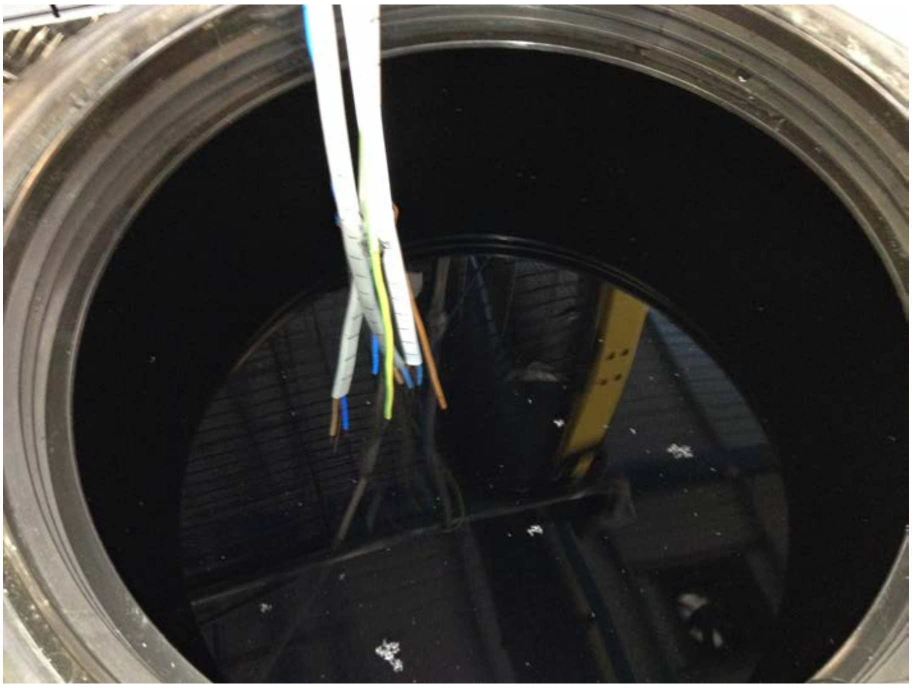

Figure 2: Arrangement of cable ends dipped into the liquid (Protocol 1 – Wicking).

Figure 3: Condition of the cables after Protocol 2 - Penetration.

Figure 4: Condition of cables after Protocol 4 – Medium Term Immersion Insulation Resistance. Left to right: silty, salty, clean. Grey cables: PVC; white cable: LSHF.

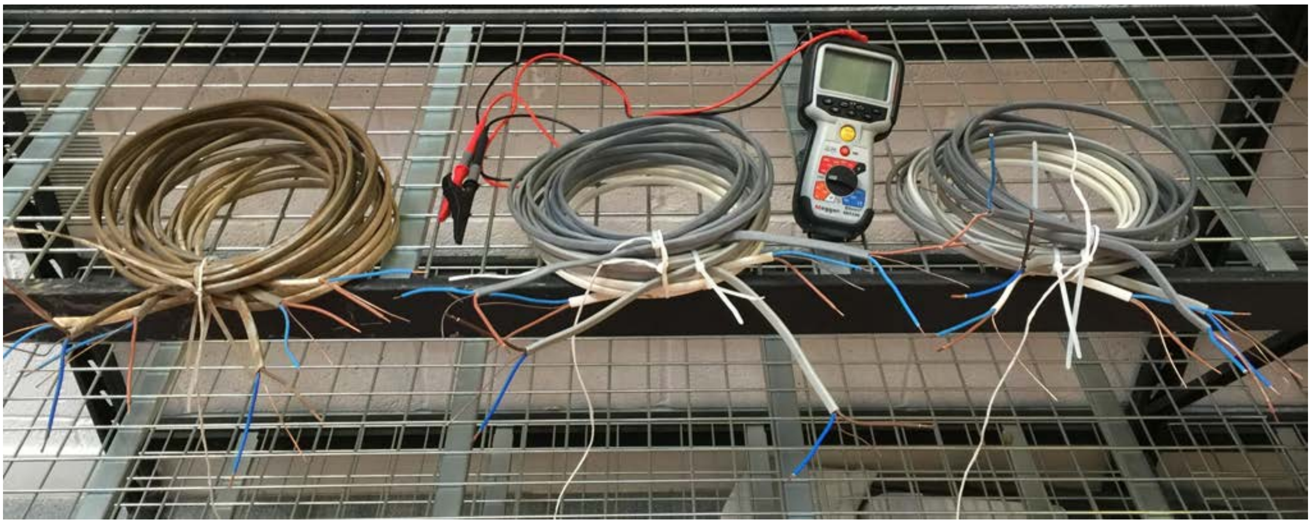

Figure 5: Condition of cables and drying arrangements after Protocol 5 – Model Flood, Insulation Resistance on Drying. Left to right: silty, salty, clean. Grey cables: PVC; white cable: LSHF.

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